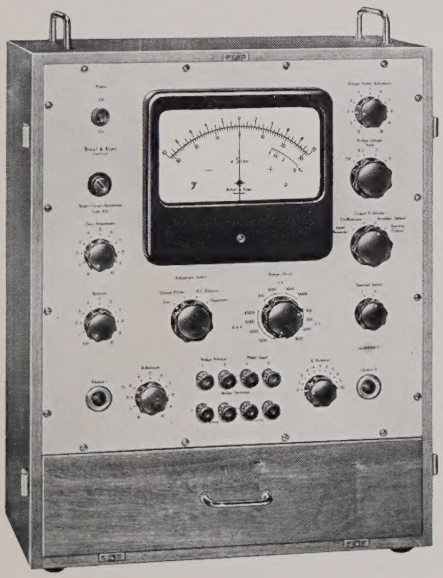
1516

INSTRUCTIONS AND APPLICATIONS

Strain Gage Apparatus Type 1516



Static and Dynamic Measurements.
0—100 kHz Frequency Range.
25 to 30000 μStrain for Full Deflection.
Half and full Strain Gage Bridge Connections.
External Indicating Instrument Connection.

Accessories

Accelerometers
Acoustic Standing Wave Apparatus
Artificial Ears
Artificial Voices
Audio Frequency Response Tracers
Audio Frequency Spectrometers
Audio Frequency Vacuum-Tube Voltmeters
Automatic A. F.Response and Spectrum Recorders
Automatic Vibration-Exciter Control Generators
Band-Pass Filter Sets
Beat Frequency Oscillators
Complex Modulus Apparatus
Condenser Microphones
Deviation Bridges
Distortion Measuring Bridges
Frequency Analyzers
Frequency Measuring Bridges
Hearing Aid Test Apparatus
Heterodyne Voltmeters
Level Recorders
Megohmmeters
Microphone Accessories
Microphone Amplifiers
Microphone Calibration Apparatus
Mobile Laboratories
Noise Generators
Noise Limit Indicators
Pistonphones
Polar Diagram Recorders
Preamplifiers
Precision Sound Level Meters
Recording Paper
Strain Gage Apparatus and Accessories
Surface Roughness Meters
Variable Frequency Rejection Filters
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Vibration Pick-ups
Vibration Pick-up Preamplifiers
Wide Range Vacuum Tube Voltmeters

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Strain Gage Apparatus

Type 1516

Accessories

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Introduction

General.

The Strain Gage Apparatus Type 1516 is intended for direct reading of dynamic and static deformations in materials,*) resistance strain gages being used as the sensitive or detecting elements.

The Strain Gage Apparatus, when used with suitable strain gages, may be employed over the whole field of non-destructive material investigation and stress analysis. Bending and torsion, as well as pure tension and compression, may be investigated and studied. Further, the strain gage technique may be employed to determine numerous physical quantities such as temperature and weight, fluid levels, pressure changes in pumps, pipes and internal combustion engines; it may also be used for explosion analysis and for investigation of a host of other problems.

Resistance Strain Gages.

As resistance strain gages have to be used for measurement with the Strain Gage Apparatus, a brief introduction to the subject of these gages and how they function is given in the following.

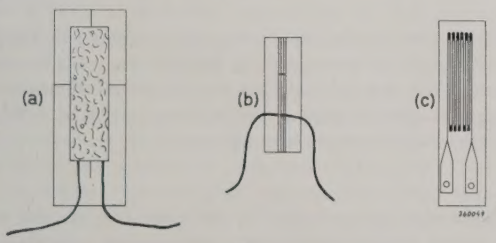

Fig. 1. Three types of strain gage.

*) The apparatus measures relative deformation.

Relative deformation = Strain = e (or ε) = $\frac{\Delta l}{l}$ cm/cm or inches/inches.

1 μStrain = 10^{-6} Strain.

Design. The resistance strain gage consists of a small sensitive element, formed by arranging an electrical conductor of small cross-sectional area into a grid. This grid is mounted on a thin carrier which may be either paper or a plastic, and in this form may be adhered to the material or structure to be investigated. In practice the electrical conductor may be either a thin wire or an etched foil grid. These two configurations form two distinct types of resistance gage, i.e. the wire gage and foil gage.

Wire gages. Fig. 1a and 1b illustrate the wire gages. The gage shown in Fig. 1a is mounted on a paper base. The grid has been formed either in a zig-zag fashion, or has been wound as a helix and then flattened. The grid is sandwiched between two layers of thin paper and the whole glued together with a bakelite or celluloid varnish. The type of adhesive employed in the construction of the gage can also be used to fix it to the structure under examination. The gage in Fig. 1b is on a phenolic base. The resistance wires, which are continuous the whole length of the gage, are joined by thick cross-wires to form a grid. The advantages of this gage are that its conductors are parallel and the cross-sensitivity low.

Foil gages. Fig. 1c shows an example of an etched foil gage. The gage element is of etched cupro-nickel alloy on an epoxy-ethylene lacquer backing. This gage has the advantages of high current carrying capacity and low cross-sensitivity.

The strain gages are available in several configurations:—

(1) Torque gages for measuring the torque in rotating shafts by utilising the shear stress present.

(2) Rosette gages by means of which the resultant of a complex strain in a structure can be determined in direction and magnitude.

(3) Diaphragm gages that utilise the deflection of a diaphragm exposed to two different pressures. These are used in such items as pressure transducers.

To avoid hysteresis effect during application it is essential that good adhesion exists between the gage and the surface of the member being investigated. It is also advisable that the gage element be as close to the member as possible. With good gages the grid element is between 2.5 and 10×10^{-3} cm from the surface of the material to which it is affixed.

Function. The principle of operation of the gage is, that if a conductor is subjected to an axial strain, it will suffer a change in resistance, the change in resistance per unit strain being dependent on the particular conductor material and shape employed. When the material to which the gages are attached experiences a tensile or compressive strain, the strain is transferred to the gage element which will change its resistance according to the relationship $R = \frac{\varrho \times l}{a}$

where

R = resistance ohms
ϱ = specific resistance of conductor material
l = length of conductor
a = area of conductor.

When the gage is stretched the conductor length l increases, its cross-sectional area a decreases, and there is a relative resistance alteration. The relation between the strain of the gage and the change in resistance is given by

$$\frac{\Delta l}{l} \times k = \frac{\Delta R}{R}$$

where k is the gage factor of the gage in question.

$$k = \frac{\frac{\Delta R}{R}}{\frac{\Delta l}{l}} = \frac{\frac{\Delta R}{R}}{e}$$

The k factor will vary with different materials, for it is dependent on Poisson's ratio. Another contributory factor is the change in specific resistance which occurs as the result of crystal lattice deformation. As it seems that it might be possible to obtain a very high gage factor with the right alloy, it should be pointed out that it is most desirable that the resistance of the gage should change but little with temperature variation within the temperature limits over which the gage is required to operate, i.e. the conductor material must have a low temperature coefficient of resistivity, which is unfortunately not the case with alloys comprising high gage factors. Thus the gage factor of most gages has a value between 1.8 and 3.0, a fair compromise between sensitivity and stability existing under these conditions.

Temperature Effect. A difficulty introduced by temperature variation is that almost all materials which may have to be strain-gaged experience a dimensional change with change of temperature. The coefficient of linear expansion of iron for example, is 1.2×10^{-5}/ °C. Now as Young's modulus is approximately 2×10^6 kg/ cm^2, it will be seen that a temperature change of 1° C will produce a change in gage resistance equivalent to that which would be produced by a stress of 24 kg/cm^2 in the iron. (The effects due to differential expansion between gage and member being ignored.) In order to eliminate the undesirable effect of this unavoidable thermal expansion, strain gages may be used in pairs, one of which (the active) is attached to the material at the point where it is desired to measure the relative increase in length. The other (the dummy) is attached in the immediate vicinity of the active gage on a piece of the same material which is without strain, but has the same temperature as the measuring point. The two strain gages are then coupled into a bridge circuit in such a way that a dimensional change caused by temperature change is compensated. If it is desired to measure

with two or four active gages this method of compensation will also automatically follow.

Modes of Connection. The strain gages are usually connected in the form of a Wheatstone bridge (vide Fig. 2a and b) but there need not necessarily be a full bridge of gages (Fig. 2a), in fact such is rarely the case. Two gages are

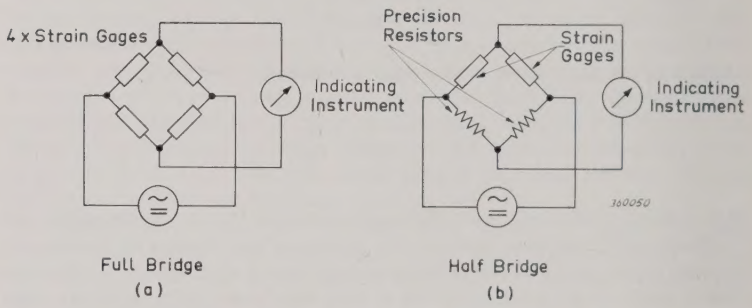

Fig. 2. Strain gages connected as a Wheatstone Bridge.

thus combined with two precision resistors (Fig. 2b). This configuration is normally called a half bridge. The bridge is supplied with either AC or DC and the bridge output signal fed into some form of instrumentation suitable for the particular application.

Signal Output from Bridge. With four equal resistors R in a Wheatstone bridge, and the supply voltage connected across one diagonal the voltage across the other diagonal will be zero. A change in resistance of Δ R in one

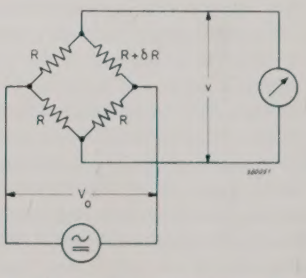

Fig. 3. Unbalanced Wheatstone Bridge.

of the bridge arms, will produce a voltage across the bridge diagonal of v volts, which is measured by the indicating instrumentation (vide Fig. 3),

$$v \simeq \frac{\Delta R}{4R} \times V_o \qquad (1)$$

Where, R = resistance of one arm and V_o = bridge supply voltage.
It is assumed that the impedance of the measuring instrument is large compared with R.

By definition the gage factor, $k = \dfrac{\dfrac{\Delta R}{R}}{\dfrac{\Delta l}{l}} = \dfrac{\dfrac{\Delta R}{R}}{e}$

substitute in (1) which gives:—

$$v \simeq \frac{1}{4} k e V_o \text{ volts.} \qquad (2)$$

Description

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Description

General.

The Strain Gage Apparatus contains a 3 kHz oscillator which feeds a Wheatstone bridge, consisting of two or four strain gages (see Fig. 4). When using only two strain gages the other two bridge arms are formed by fixed resistors which are either within the apparatus (with the TERMINAL SWITCH on "II"—see Fig. 4), or outside the apparatus, incorporated in each of the various auxiliary equipments Types 1530, 1531, 1534, 1542 and 1543 (TERMINAL SWITCH on "I").

The signal output voltage from the bridge is amplified in a four-stage amplifier, the output of which, together with a portion of the oscillator voltage, is fed to a phase-sensitive rectifier circuit.

A zero centre indicating meter connected to the output of the phase-sensitive rectifier circuit indicates the magnitude and sense of the bridge unbalance and hence the strain. The advantages of the circuitry used are; high sensitivity to signal; insensitivity to hum (the rectifier responds only to the oscillator frequency); and phase or sense discrimination permitting tension and compression to be displayed respectively as positive and negative deflection on the meter.

Generator and Amplifier Section.

Oscillator and Bridge Supply. The 3 kHz oscillator (V_2) feeds the bridge supply tube V_1 through a capacitor and a potentiometer P_1. V_2 also supplies, via T_3, the phase-sensitive rectifier circuit and an output from the cathode is used as a reference in the mixer tube V_6. From V_1, the 3 kHz output is fed via T_1 and various switches, to the bridge supply terminals. See Fig. 4.

Gage Factor Adjustment. From equation (2) in the "Introduction" it is seen that to obtain the same voltage v and hence the same meter deflection for a given strain e, but different gage factors, the applied voltage V_o must be varied. A potentiometer P1 GAGE FACTOR ADJUSTMENT is therefore incorporated, enabling the bridge supply voltage to be varied to suit the gage factor of the gage used. A small subsidiary scale on the indicating meter is graduated in k values to facilitate the necessary adjustment.

Strain Range Adjustment. In order that the maximum strain range can be accommodated, three different bridge voltages are provided at nominal values of 0.3, 1.0 and 3.0 volts. These voltages are taken from three second

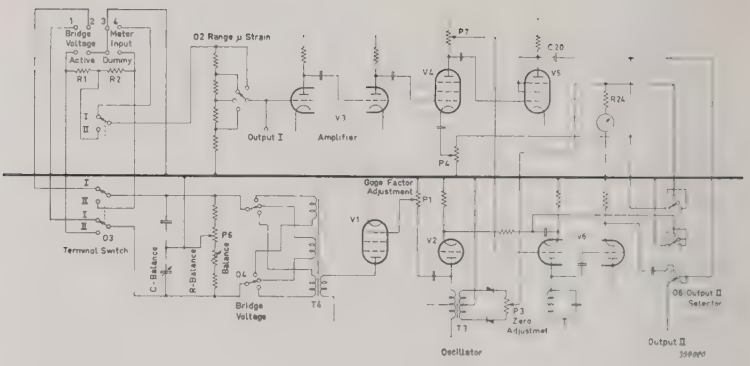

Fig. 4. Schematic diagram of Strain Gage Apparatus.

ary windings on transformer T_4, and are switched to the supply terminals by the switch marked BRIDGE VOLTAGE.

An input attenuator in the signal amplifier enables a further choice of four full-scale deflection values for each voltage, the attenuator is controlled by the RANGE μSTRAIN switch and the full deflection for each voltage are indicated around the switch. The most sensitive range obtainable is 100 μStrain full-scale deflection, and the least sensitive 30000 μStrain. These values are valid for normal strain measurements with one active and one dummy strain gage and two fixed resistors. With two active gages arranged for maximum sensitivity,the meter reading must be halved. All types of strain gages with resistances between 10 and 1000 Ω may be used.

Terminal Connections. With the TERMINAL SWITCH on "I", the oscillator voltage is available on terminals 1 and 2, and the signal voltage from the bridge should be fed on terminals 3 and 4. The TERMINAL SWITCH should be on "I" when it is desired to use four strain gages or auxiliary equipment. When the TERMINAL SWITCH is on "II" the active and dummy gage should be connected as indicated. See Fig. 4. In this position two internal resistors of 100 Ω are connected to form a full bridge, in conjunction with the active and dummy gage.

Signal Amplifier. The signal voltage from the bridge is led to the first stage in the amplifier via the RANGE μSTRAIN attenuator. The three amplifier tubes V_3, V_4 and V_5 are DC-heated to reduce hum voltage. The DC voltage is taken from a selenium rectifier in the apparatus. The first amplifier tube V_3, being a double triode, works as a two-stage amplifier with a negative feedback. This makes the amplifier feature a very low noise and micro

phonic level. Feedback, applied over the last two stages ensures constant amplification and low output impedance. The feedback can be adjusted by means of P_4. (The adjustment is carried out at the factory). The frequency response of the amplifier is flat from 20 Hz to 100 kHz, within 1 dB, and the gain is about 80 dB. The signal from the amplifier is directed, via the ADJUSTMENT SWITCH and OUTPUT II SELECTOR to the phase-sensitive rectifier and built-in indicating instrument. Various recording and display instruments can be connected to the OUTPUT II socket, depending on the position of the OUTPUT II SELECTOR switch.

Adjustment Switch. The ADJUSTMENT SWITCH (Fig. 7) designates the adjustments which should be carried out prior to taking measurements.

Zero. With the ADJUSTMENT SWITCH on "Zero" the meter indication should be brought to the zero value in the middle of the scale by means of the knob ZERO ADJUSTMENT. The amplifier input is at this stage short-circuited and the phase-sensitive rectifier is balanced by the ZERO ADJUSTMENT potentiometer, P_3.

Gage Factor. With the ADJUSTMENT SWITCH on "Gage Factor" the meter indication should be brought, by means of the GAGE FACTOR ADJUSTMENT, to a value corresponding the the gage factor, k. The small subsidiary scale on the right side of the meter is used for this purpose. A portion of the bridge supply voltage is fed via calibrated resistors and a measuring transformer to the amplifier input, and then to the meter circuit, so that this adjustment can be made.

R-C Balance. A Wheatstone bridge, consisting of two fixed resistors and two strain gages, or four strain gages, will always be in slight unbalance due to

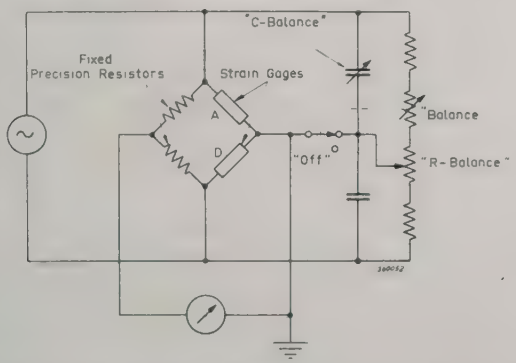

Fig. 5. Principle of R and C balancing. Also valid when the two fixed precision resistors are interchanged by two strain gages.

small differences between the components, the capacitive influence of the wiring, etc. With the extreme sensitivity necessary for strain gage measurement any unbalance in the bridge has to be completely eliminated before measurements are taken. In order to achieve perfect balance both an R and C balance are incorporated in the instrument, consisting of a set of resistors and capacitors across the bridge supply. (In Fig. 5 the basic circuit is illustrated.)

The components are adjusted by three knobs, R-BALANCE, C-BALANCE, and a fine resistance control, BALANCE. When auxiliary equipment is connected in the circuit using Terminals I, and when these units have their own independent R-C balancing, the latter should be used, and the R-C balancing in the apparatus switched out by turning the BALANCE knob to the "Off" position.

When the ADJUSTMENT SWITCH is on "R-C Balance", the phase-sensitive rectifier is cut out, and the rectified amplifier output goes direct to the meter. The meter now shows the amplitude of the signal voltage from the bridge, BD (Fig. 6a), and not that component of the voltage which has the same phase as the oscillator voltage (BD_1 Fig. 6b), as is the case when the phase-sensitive rectifier is operating. This rectifier functions in the same manner as a ring modulator. When no phase difference exists between the inserted signal and the voltage appearing across one of the windings of T_3, the total signal is measured; a phase change of 180° between the two voltages

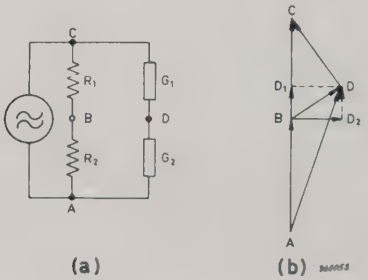

Fig. 6. Vector diagram of bridge voltages.

will merely reverse the direction of current flow. However, if there is a 90° phase shift there will be equal currents in both directions through the meter, with a resulting zero meter deflection. It is for this reason necessary, when balancing, to switch the rectifier out of circuit. If the rectifier was left in, the capacitive voltage BD_2 might be large enough to overload the amplifier, before any resistive unbalance had taken place.

The vector diagram, Fig. 6b, illustrates the condition in Fig. 6a, in which two fixed resistors and two strain gages are employed. See also Fig. 2b.

The bridge supply voltage, AC, is divided between the two strain gages as AD and DC. The magnitude and phase of these voltages will depend on the resistive and reactive components of G_1 and G_2. In order that the voltage across BD may be reduced to zero the "Adjustment Switch" is turned to "R-C Balance", the resistive and capacitive balance controls being adjusted to give zero meter reading, i.e. BD = 0. The meter should thus always be zeroed before measurements are taken. Because the rectified diagonal voltage is always of the same polarity, the meter will show only a positive deflection when balancing.

Operation. In the measurement of strain it is advantageous to obtain positive or negative meter deflection, depending on whether the active gage is being subjected to tension or compression, i.e. whether the resistance of the active gage is greater or smaller than the dummy. By introducing the phase-sensitive rectifier, current may flow in either direction through the meter, depending on whether BD_1, which is the only component now measured, has the direction B-C, or B-A (see vector diagram Fig. 6b). Thus a positive meter deflection will correspond to tension, a negative deflection to compression. With the ADJUSTMENT SWITCH on "Operation" the phase-sensitive rectifier is again brought into use, and measurements may be taken. For direct indication of tension and compression on the instrument meter, the OUTPUT II SELECTOR may be set to position 1, "Level Recorder", or 2, "Oscilloscope". In position 3 the meter is cut out, while in position 4 a load on OUTPUT II less than 50 kΩ will influence the meter reading.

Recording or Indicating Instruments on Output I and II. The built-in meter is unsuitable for dynamic measurements, an external instrument connected to output I or II will therefore be necessary. It is also advisable to use an external recording apparatus when slowly varying phenomena are being studied. The characteristics of the external instrument employed, together with those of the amplifier in Type 1516, will determine the frequency range of the dynamic phenomena which the combination can cover.

OUTPUT I is intended to feed a cathode-ray oscilloscope possessing high amplification when DC Bridge Supply Unit Type 1535 is used. See p. 40. The output to the oscilloscope is taken before the amplifier, consequently the OUTPUT II SELECTOR does not have any control.

Output II Selector. Various recording and indicating instruments can be used on OUTPUT II as indicated in the following table, the position of the OUTPUT II SELECTOR and type of bridge voltage is also noted.

OUTPUT II SELECTOR in position	Level Recorder	Oscilloscope	Amplifier Output		Rectifier Output	
Recording Instrument	Level Recorder	Oscilloscope	Oscilloscope	Oscilloscope	Pen Recorder	Oscilloscope
Useful Frequency Range Hz	0—15	0—200	0—300	20—100000	0—100	0—100
Bridge Supply	AC	AC	AC	DC	AC	AC
Typical output voltage corresponding to full scale deflection. Volts	0.15—0.6	0.25	2		0.4 DC	
Maximum output voltage available over a 50 kΩ load	—	1.0	20		—	
Output Impedance, kΩ approximately	3	3	0.6		1.2	
See Remark	1	2	3	4	5	6

Remarks on the Table.

1. In this position of the OUTPUT II SELECTOR the output voltage is taken from a mixer tube V_6 via a cathode follower (refer Fig. 4 on page 10). One of the inputs to the mixer is a constant amplitude signal, derived from the oscillator cathode, the second input to the mixer is taken from a potentiometer P_7 which forms a part of the anode load of the second amplifier tube V_4. By means of this arrangement it is possible to obtain correlation between the scale of the Level Recorder Type 2305 (when used with a linear potentiometer ZR 0001) and the scale of the Strain Gage Apparatus. Thus the Level Recorder indicates 0, 25, 50 mm. (when 50 mm. width paper is used) or 0, 50, 100 mm. (when 100 mm. paper) for meter readings on the Strain Gage Apparatus of — 10, 0, + 10 respectively.

The mixer tube is in fact a phase-sensitive device. Depending on whether the signal voltage from V_4 is in phase or anti-phase with the signal from the oscillator cathode, the output from the mixer tube will be increased or decreased compared to the output obtained for zero deflection, i.e. no signal from V_4. Tension is thus recorded as a stylus deflection between the middle point and maximum on the level recorder scale, and compression as a deflection between middle point and minimum. When recording dynamic phenomena, the signal from the bridge will be a 3 kHz carrier, amplitude modulated at the frequency of the dynamic strain. The signal is detected in the Level Recorder, the writing system of which can follow up to approximately 5 Hz with maximum deflection. If both a static and a dynamic strain are imposed, the recording will show both components correctly, irrespective of their relative magnitudes. Adjustment is made to the "no

signal" position of the stylus with the aid of the INPUT ATTENUATOR and INPUT POTENTIOMETER on the Level Recorder. The position of the potentiometer P_7 in the anode load of the second amplifier tube V_4, determines the signal required for full-scale deflection. Hum and noise in the mixer output are reduced to a minimum by employing a selective circuit, tuned to 3 kHz, in the anode circuit of the mixer.

2. As in the former position the output is taken from the cathode follower. The reference output from the oscillator cathode is put to ground. The tuned network remains in circuit making this output condition particularly suitable for recording dynamic signals between 0—200 Hz, with the aid of an oscilloscope and camera.
With the reference signal short-circuited, only the amplifier signal reaches the output, tension and compression will therefore be depicted on the oscilloscope screen as a signal of a certain amplitude of 3 kHz. From the deflection of the meter in the Strain Gage Apparatus it can be seen whether a tensile or compressive case exists. When static and dynamic strains are being recorded together, in which the dynamic strain is the greater, overmodulation will occur, vide Fig. 25d on page 38. The variable Balancing Unit Type 1533 should be used in this case to separate the components of the applied strain.

3. In this position the bridge output is connected directly to the main amplifier, whilst the phase-sensitive rectifier and indicating meter are cut out of circuit. The meter deflection will always be zero with OUTPUT II SELECTOR in this position. There is no filter now in the output circuit, consequently the influence of noise and hum will be greater. However, with the filter out of circuit, dynamic measurements with frequencies up to 300 Hz can be accommodated, the output should be displayed on an oscilloscope as in point 2.

4. It is when purely dynamic strains, having a frequency that may be in excess of 300 Hz, are measured that the "Amplifier Output" position is of most use. In such a case the DC Bridge Supply Unit Type 1535 supplies the bridge voltage, the BRIDGE VOLTAGE switch on Type 1516 being switched to "Off". Vibration signals from 20 Hz to 100 kHz will then be directly amplified and may be observed on a cathode-ray oscilloscope. Photographic recordings may of course be taken.

5. In this position of the OUTPUT II SELECTOR, OUTPUT II is connected across the phase-sensitive rectifier. The unsmoothed, rectified signal of 3 kHz will be amplitude modulated by dynamic strain. The signal may be applied to a pen recorder, which covers the desired frequency range.

6. If an oscilloscope is used in the "Rectifier Output" position a Low Pass Filter Type 1538 is necessary, in order to remove the 3 kHz component of the rectified signal. Dynamic strains from 0—100 Hz can be displayed on an oscilloscope. This system differs from that discussed in point 2, in that, over-

modulation cannot occur. If the bridge is initially zeroed, tensile loads will deflect the cathode-ray oscilloscope beam in one direction, and compressive loads in the other.

Power Supply.

The Strain Gage Apparatus can be operated from an AC power supply of 100, 115, 127, 150, 220 or 240 volts. The frequency is not critical, but should be within the range 40—400 Hz. The anode and screen grid voltage supply for the amplifier tubes is stabilized, and to keep the hum level at a low value the tubes in the amplifier are heated by a stabilized DC from a selenium rectifier. The total power consumption is about 65 watts.

Mains voltage stabilization should be used in situations where the fluctuations in the mains voltage creates trouble in spite of the mentioned stabilization.

The adjustment to one of the six voltages is carried out by a voltage selector on the rear of the equipment. Refer Fig. 8. The fuse, which is in circuit with the primary side of the power transformer should first be removed before the inner part of the combined voltage selector and fuse holder can be turned to the proper value.

If it is desired to operate the Strain Gage Apparatus from a DC line or an accumulator, it will be necessary to use a vibrator or a rotary converter.

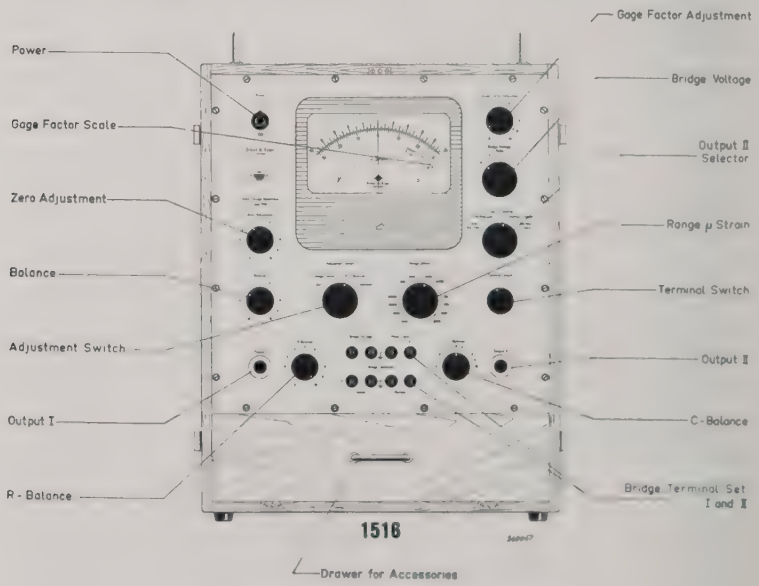

Fig. 7. Front Panel Strain Gage Apparatus.

Identification of Control Knobs, Terminals, etc.

Front Plate. (Refer Fig. 7)

"Power": For switching on and off the apparatus. When switched on the meter scale is illuminated.

"Zero Adjustment": For balancing of the phase-sensitive detector. Correct balance is indicated by zero deflection on indicating meter.

"Balance": For fine-adjustment of the R-balance.
"Off", the built-in R- and C-balancing components are disconnected. (To be used when external R- and C-balancing).

"Adjustment Switch": To be operated during calibration and adjustment of apparatus.
"Zero": Zero setting of indicating meter by means of ZERO ADJUSTMENT.
"Gage Factor": Adjustment to actual gage factor on subsidary meter scale by GAGE FACTOR ADJUSTMENT.
"R-C-Balance": Balancing of the connected bridge by R-BALANCE and C-BALANCE controls.
"Operation": For measurements.

"Output I": For external indicating instruments. Direct DC connection to the bridge diagonal via the attenuator RANGE μSTRAIN.

"R-Balance": Resistive balancing of bridge. In operation when BALANCE to position "1—10" independent of the position of the TERMINAL SWITCH.

"Gage Factor Adjustment": For calibration of apparatus, according to gage factor of the gage in use.

"Bridge Voltage": For magnitude selection of the internal 3 kHz voltage.

"o.3", "1" or "3" volt is present on the bridge diagonal when set to Gage Factor "2".

"Off". External bridge voltage has to be supplied e.g. by the DC Bridge Supply Unit Type 1535.

"Output II Selector": To give the output signal various characteristics to suit external indicating instruments. See also the table on page 14.

"Level Recorder": An amplitude modulated bias voltage of 3 kHz is present. Intended for recording on the B & K Level Recorder Type 2305.

"Oscilloscope": An amplitude modulated voltage of 3 kHz is present. Intended for display on an oscilloscope.

"Amplifier Output": The measuring amplifier is connected direct to the output.
To be used when the strain gage bridge is DC-supplied for dynamic measurements. The meter is disconnected when ADJUSTMENT SWITCH in position "Operation".

"Rectifier Output": The output is connected across the indicating instrument. A half-wave rectified and unsmoothed polarized bridge supply voltage (3 kHz) is present.
To be used for DC indicating instruments.

"Range μStrain": Four ranges of sensitivity can be selected for the bridge voltages o.3, 1 and 3 volts. Values, indicated by knob position, valid for full-scale deflection.

"Terminal Switch": For selection of BRIDGE TERMINAL SET I or II.

"Output II": For external indicating instruments. Various output properties selectable by OUTPUT II SELECTOR.

"C-Balance": Capacitive balancing of bridge. In operation when BALANCE is in position "1—10" independent of the position of the TERMINAL SWITCH.

"Bridge Terminals I": For connection of full bridges or accessories Type 1530, 1531, 1534, 1535 or 1542. In operation when TERMINAL SWITCH is in position "I".

"Bridge Terminals II": For connection of half strain gage bridges. When DUMMY and ACTIVE gage is connected as indicated, the meter gives "+" deflection for tensile strain, and "—" for compressive. In operation when TERMINAL SWITCH is in position "II".

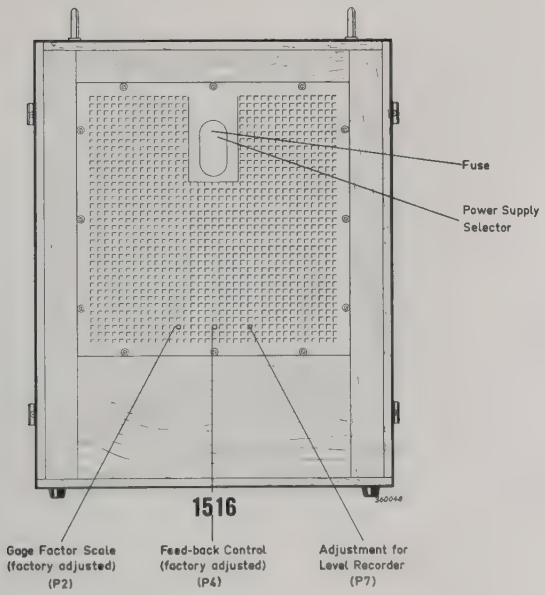

Fig. 8. Rear view of Strain Gage Apparatus.

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Operation

Strain Gage Apparatus.

A. Adjustment.

1. Check that the power supply voltage selector is set to the proper voltage. If not, remove the fuse (see Fig. 8)) and turn the middle portion of the combined fuse holder and selector until the white mark rests opposite the proper voltage. Replace the fuse and switch "Power" to "On". The scale should immediately be illuminated. After a few minutes of warming-up, the apparatus can then be adjusted.
2. Connect strain gages or accessories as given below:—
   (a) Full bridge (see also Figs. 15 and 17) or accessories are connected to BRIDGE TERMINAL SET I.
   (b) Half bridge (see also Figs. 14 and 16) is connected to BRIDGE TERMINAL SET II.
   NOTE: In order to avoid inaccuracy the system should be carefully grounded. Terminal 3 should be made the earth point at all times.
3. Set control knobs to:—
   (a) TERMINAL SWITCH to appropriate position.
   (b) OUTPUT II SELECTOR on "Level Recorder".
   (c) BRIDGE VOLTAGE suitable for the gage and the measurement to be undertaken.
   (d) ADJUSTMENT SWITCH on "Zero".
4. Zero adjust indicating meter with ZERO ADJUSTMENT
5. Set ADJUSTMENT SWITCH on "Gage Factor".
6. Adjust to the gage factor valid for the gages with GAGE FACTOR ADJUSTMENT. (To be set on the indicating meter gage factor scale).
   (a) Gage factors 1.5 to 3.
   Adjust indicating meter deflection to actual gage factor.
   (b) Gage factor 0.75 to 1.5.
   Adjust indicating meter deflection to:—
   2 × actual gage factor.
   Measured results are multiplied by 2.
   (c) Gage factor 3 to 6.
   Adjust indicating meter deflection to:—
   ½ × actual gage factor.
   Measured results are multiplied by ½

(d) Generally, with any gage factor k outside the range 1.5 -3, the meter deflection is adjusted to the value $k' = a\,k$, where $1.5 \leqq k' \leqq 3$, and k is the actual gage factor. It then follows for the actual strain e, $e = ae'$ where e' is the deflection read off the meter and RANGE μSTRAIN scale.

7. Set RANGE μSTRAIN to a position of minimum sensitivity, i.e. fully clockwise.
8. Set ADJUSTMENT SWITCH to "R-C Balance".
9. Balance strain gage bridge as outlined:—
   (a) Bridge connected direct to Strain Gage Apparatus:—
      1. Balance bridge by R-BALANCE and C-BALANCE. Balance is indicated by zero deflection on indicating meter, whereas unbalance by a deflection to the right.

         NOTE: In rare cases the deflection of the meter might not be brought inside the scale graduation even with the RANGE μSTRAIN switch to the maximum clockwise position (less sensitive). To assist in detection of possible faults in connections or gage resistance the GAGE FACTOR ADJUSTMENT is turned anti-clockwise until the deflection appears within the scale graduation. Prior to continuing the balancing the GAGE FACTOR ADJUSTMENT is reset as in item 6.

      2. Continue the balancing process at higher and higher degrees of sensitivity by altering the RANGE μSTRAIN step-by-step, until balance is achieved in the most sensitive position of this control i.e. fully anti-clockwise.

         NOTE: If the magnitude of unbalance is outside the range of the balancing components in the Strain Gage Apparatus, or of the accessories described later in this booklet, one or more Fixed Balancing Resistors Type 1540 or Fixed Balancing Condensers Type 1541 can be employed. As the resistive balancing components affect the measuring accuracy, reference should be made to Appendix, page 77, when used. The units, fitted with banana pins, may be inserted into the connection terminals on the Type 1516, or any of the other accessories. The alteration produced by one of these units shunting a bridge arm is equal to the whole range of the R- and C-balancing controls in the Strain Gage Apparatus Type 1516, or any of the mentioned accessories.

   (b) Accessories connected to the Strain Gage Apparatus:-
      1. Set BALANCE to "Off", balance bridges by the R and C

balance components on the accessories by following item 9(a) 1 and 2.

10. Place ADJUSTMENT SWITCH to "Operation".
11. Readjust any unbalance by:—
    (a) BALANCE if strain gages are connected direct to the Strain Gage Apparatus.
    (b) R-BALANCE on the accessory if this is employed.
12. For the measurement choose the appropriate measuring range by RANGE μSTRAIN and, if necessary, by BRIDGE VOLTAGE.

    NOTE: When the position of the BRIDGE VOLTAGE is changed from position chosen under item 3(c), item 6 has to be repeated.

The Strain Gage Apparatus is now ready for measurement.

B. Reading from Indicating Meter.

Strain is read directly in μStrain*) on the scale, taking into account the selected position of BRIDGE VOLTAGE and RANGE μSTRAIN.

As the Strain Gage Apparatus is calibrated for measurements employing one active gage only, the readings must be multiplied by ½ when two active gages are used. With four active gages the multiplication factor is ¼.

Recording with Level Recorder Type 2305.

When the Level Recorder is employed to register the measurements carried out with the Strain Gage Apparatus, a recording is obtained on 50 mm or 100 mm paper as desired. For further information on the Level Recorder reference should be made to the manual for this apparatus.

The Level Recorder can be used for static and low-frequency dynamic measurements, or a combination of both. In Fig. 9 is shown the performance

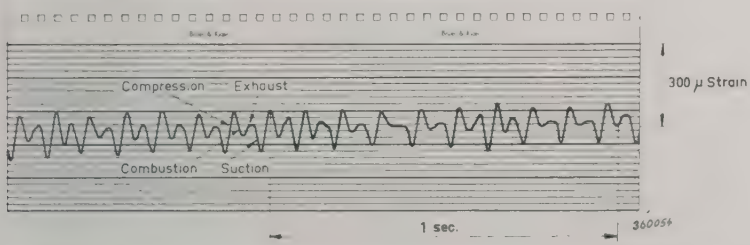

Fig. 9. Amplitude-time recording of strain in the connecting rod of a one-cylinder four-stroke combustion engine.

*) 1 μStrain = 10^{-6} cm/cm (inch/inch).

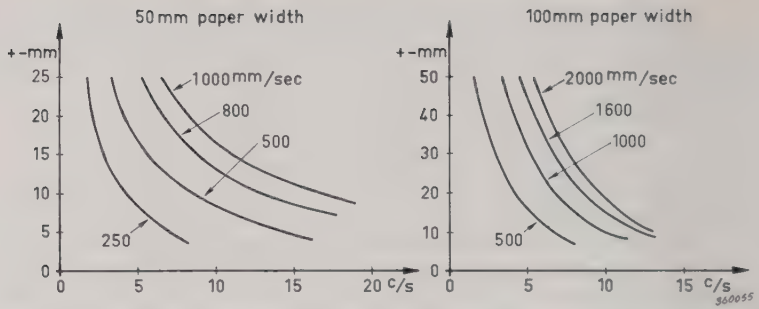

Fig. 10. Maximum amplitude of sine wave signal versus frequency (writing speed as parameter), which can be amplitude recorded by the Level Recorder when this is connected to the Strain Gage Apparatus.

of dynamic strain in the connecting rod on a one-cylinder four-stroke combustion engine under working conditions. Recording the instantaneous amplitude of signals with frequencies up to approximately 5 Hz is possible for sine waves, when the whole width of the paper is utilized. When a smaller deflection on the paper is satisfactory, the frequency can accordingly be higher. In Fig. 10 is shown the practically distortion-free stylus deflection versus frequency for sine waves.

Set-up and Calibration. The 10—35 mV Range Potentiometer (ZR 0001) should be inserted in the Level Recorder, and it is recommended to use the recording paper types QP 0102, QP 0202 or QP 0302 (50 mm width), QP 1102 (100 mm width).

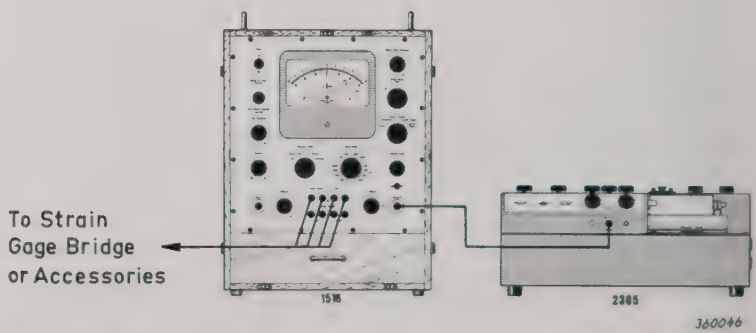

Fig. 11. Level Recorder Type 2305 connected to the Strain Gage Apparatus.

Operate as outlined in the following:—

1. Connect the two apparatus as shown in Fig. 11.
2. Adjust the Strain Gage Apparatus as layed out in the previous chapter, Strain Gage Apparatus, page 21 (item 1 through 12). The OUTPUT II SELECTOR is kept in position "Level Recorder".
3. The control knobs on the Level Recorder are positioned as follows:—
   POTENTIOMETER RANGE: "10"
   RECTIFIER RESPONSE: "RMS", "Average" or "Peak".
   LOWER LIMITING FREQUENCY: "200"
   Other knobs are set as desired for the measurement and as laid down in the manual for the Level Recorder.
4. While the Strain Gage Apparatus is in the "Operation" condition and its indicating meter on zero, the deflection of the stylus on the Level Recorder is adjusted by means of its INPUT ATTENUATOR and INPUT POTENTIOMETER to the middle point on the level recorder scale, i.e.
   to "25" when using 50 mm paper
   to "50" when using 100 mm paper
   NOTE: When the Strain Gage Apparatus is in position "Operation" eventual C-unbalance will not be noticeable on the indicating meter but gives inaccuracy by the following calibration of the Level Recorder.
5. By operating the R-BALANCE on the Strain Gage Apparatus the indicating meter is given a deflection to "+ 8". The stylus should now deflect to "45" or "90" respectively. If this is not the case the lower right potentiometer on the rear of the Strain Gage Apparatus should be adjusted by means of a screwdriver, vide also Fig. 8. The R-BALANCE is afterwards operated to give "— 8" deflection on the meter, the stylus should then rest on "5" or "10" respectively. If necessary, readjustment and rechecking is performed.
   The deflections on the scales of the indicating meter and stylus now coincide when any of the μ-Strain ranges "100", "1000" or "10000" are used. The lines on the paper thus correspond to the graduation of the meter scale.

Recording with Cathode-Ray Oscilloscope.

The signal resulting from dynamic strains in the frequency range from 0—200 Hz may be observed on a cathode-ray oscilloscope. See Fig. 12b.
The display on the cathode-ray tube may be photographed, or continuous recordings may be taken by switching off the cathode-ray oscilloscope time base and using the film, passing at a suitable speed through a camera, as the time base.
The output from OUTPUT II will be in the form of a modulated signal, the carrier frequency being 3 kHz. Static as well as dynamic deformation can be measured in this way.

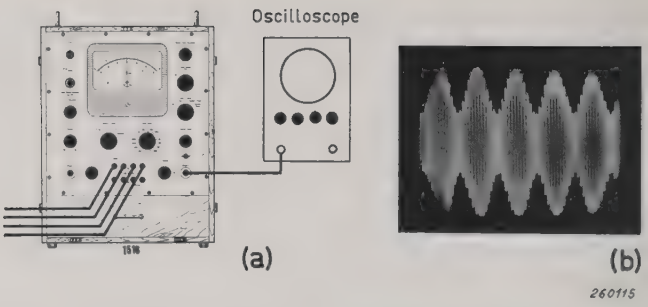

Fig. 12. Oscilloscope as indicating instrument.
(a) Measuring arrangement.
(b) Typical signal on the scope.

Set-up and Calibration. The oscilloscope should be connected to OUTPUT II of the Strain Gage Apparatus, the OUTPUT II SELECTOR being turned to "Oscilloscope".

Calibration of the oscilloscope is achieved by producing an artificial deflection with the R-BALANCE control, the deflection on the oscilloscope is then compared with that on the indicating meter of the Strain Gage Apparatus, and a scaling factor obtained.

When the OUTPUT II SELECTOR is in the "Oscilloscope" position, a 3 kHz band-pass filter is included in the circuit, noise and hum thereby being reduced. However, due to the filter bandwidth, the maximum modulation frequency is limited to 200 Hz. If it is desired to record frequencies above 200 Hz using this system, "Amplifier Output" position is chosen on the OUTPUT II SELECTOR. The limiting factor now will be the visual definition required, the definition decreasing as the modulation frequency approaches the carrier frequency.

For recording in the frequency range 20 Hz—100 kHz see p. 40.

Some Notes on the Use of Strain Gages.

PRECAUTIONS AGAINST HUM AND NOISE

Powerful electrical hum and noise fields can make strain gage measurement difficult. All possible precautions should therefore be taken to reduce the influence of these fields. The presence of hum and noise voltages may be detected when the balancing procedure is being carried out. At this time the ADJUSTMENT SWITCH is in the "R-C Balance" position, and the phase-sensitive rectifier out of circuit. As has been previously explained the R-C-balance is carried out for zero deflection, any residual is due to noise and hum voltages: this residual deflection should not exceed 20 % of the full deflection.

Tracing of Spurious Signals. A check can be made to ascertain whether a fault exists in the Strain Gage Apparatus, or whether the undesired signal is external. The connections to the input terminals are removed, with the exception of the earth connection on terminal 3. TERMINAL SWITCH is set to position "I". On a fault-free equipment the residual deflection will disappear; however, if such is not the case, the apparatus should be sent for servicing, the fault most probably being in the internal power supply.
N. B. The test for noise and hum should not be carried out when using a rotary converter as these often produce much noise. A check should be made that the earth connection is properly made and that only one such connection exists. Two earth points can give rise to circulating currents and consequent measuring inaccuracies.

Earth Connection. If one strain gage is earthed, as is the case with some pressure cells, the earthed side of this gage should be connected to wire 3 by some means, e.g. via the balancing units.
In some cases a recording apparatus associated with the 1516 may be earthed, in this event an earth connection for the Strain Gage Apparatus is formed by the screening on the cable between the two units. Under such conditions the Strain Gage Apparatus should not be earthed at terminal 3. A test could be carried out to see whether it is best to earth the recorder or the Strain Gage Apparatus. The earth connection should be as short as possible, and have an effective earth contact, while the object being investigated should also be earthed.

Wiring. Where hum fields are particularly strong, or measurements are being made over long distances, it is recommended to use screened cables. The connections to 1, 2, 3 and 4 (TERMINAL SET I) are made as follows: (Refer also Fig. 13). A twin-cored screened cable is used for the bridge supply voltage, terminals 1 and 2, the screen being connected at one end to terminal 3. The signal from the bridge is fed in through a single-cored screened cable, the core being connected to terminal 4 and the screen to

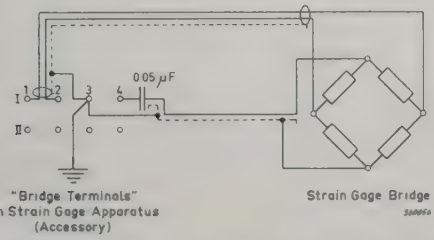

Fig. 13. Mode of connecting a full bridge to prevent effect from hum and noise. The 0.05 µF condenser in conjunction with the input impedance of the Strain Gage Apparatus acts as a high-pass filter.

terminal 3. In the event of accessories being employed this screen is used as the common earth "busbar" for all terminals marked "3".
The connections to terminals A-D (TERMINAL SET II) from the strain gages can be made with two single-cored screened cables, or with one two-cored screened cable.
Wires serving the same bridge or instrument channel should be kept together, loops in individual wires should be avoided because of the noise voltages which may be induced. The four wires connecting a Strain Gage Apparatus to a balancing unit, should be twisted together, so should the wires from the balancing unit, or Strain Gage Apparatus, to the strain gage bridge. Contact resistance at all joints and junctions should be as small as possible and in addition, stable. Connections must never be made with the aid of banana pins, or twisted wires. Screwed or soldered joints should be used at all times. It is not possible to over-emphasize the care which must be taken when wiring strain gage installations. Poor workmanship will lead to false results, and the possible need to repeat expensive tests unnecessarily. The front panels, cases, and internal screening, of all Brüel & Kjær strain gage equipments are connected internally to terminal 3. Care must be taken to ensure that if placed on a conducting surface, only the rubber feet are in contact.

High-pass Filter. If, in spite of these precautions there is still too much hum present, a high-pass filter may be inserted in the input to the amplifier, i.e. in the lead to terminal 4. The high-pass filter may only be used when measurements are being made with the 3 kHz supply. The filter is arranged so that it permits the 3 kHz carrier to pass but blocks the power supply frequency. In its simplest form the filter consists of a series condenser of approximately 0.05 μF connected in the lead to terminal 4, preferably at the terminal. Vide Fig. 13.

TEMPERATURE EFFECT

As previously mentioned, precautions should be taken to eliminate the undesirable effects of temperature variations on a strain gage installation.

Dummy Gage. False signals caused by deformation of the strain-gaged member, due to ambient temperature variations may be cancelled by using a compensating dummy gage. This dummy gage should be mounted on a small piece of material possessing characteristics identical with those of the strain-gaged member. If the dummy gage is then placed in close proximity to the active gage, temperature variations may be cancelled by this gage when the bridge connections are as shown in Fig. 14.

Hysteresis in Adhesive. Care should be taken if employing strain gages at temperatures above the normal ambient, that the adhesive used has suitable heat-resisting properties. "Gage-slip" will occur if the adhesive tends to plasticise.

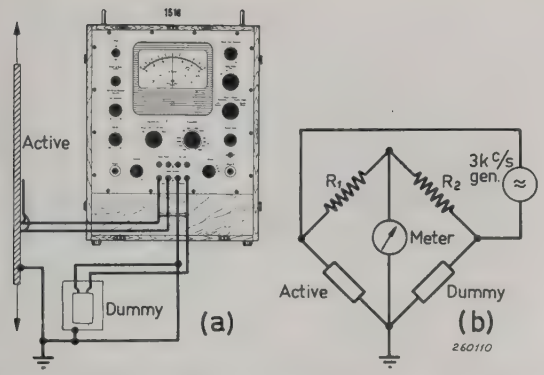

Fig. 14. Measurement of tensile strain using one active and one dummy gage.

Different Temperature Coefficients. If gages of different batches are used it is possible that the gages may possess different temperature coefficients, although the gage factors may be identical, it is almost impossible to compensate for this effect. However, gage manufacturers can supply temperature coefficient figures and give some idea of the variation to be expected, if any.

EMPLOYING MORE THAN ONE ACTIVE GAGE.

Although the scale of the 1516 is calibrated for use with one active gage there is an obvious advantage in using two active gages, particularly for small signals, as the sensitivity will be doubled.

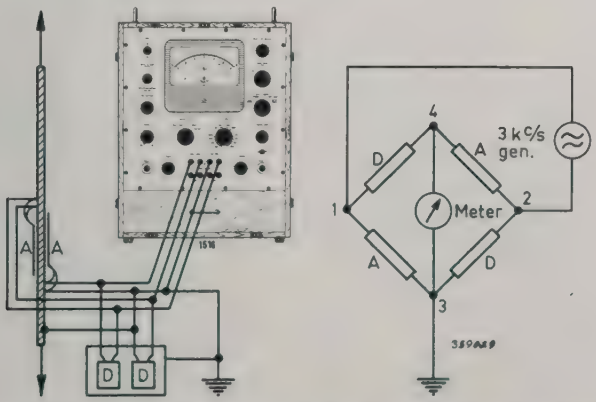

Fig. 15. Measurement of tensile strain using two active and two dummy gages.

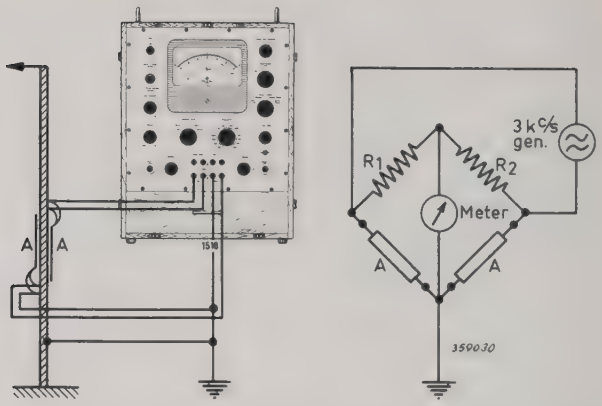

Fig. 16. Measurement of bending employing two active gages.

Fig. 15 shows two active gages being used to measure elongation. Meter readings must be multiplied by ½ for the correct reading in μStrain, if gages are thus employed. If pure bending is being measured, the measurement may be made with two active gages without using dummy gages. Fig. 16 illustrates this arrangement. Due to the gages being in adjacent bridge arms no temperature compensation is required. The meter reading must be multiplied by ½

Four active gages may also be employed when measuring pure bending, obtaining the maximum possible sensitivity, see Fig. 17. As in previous

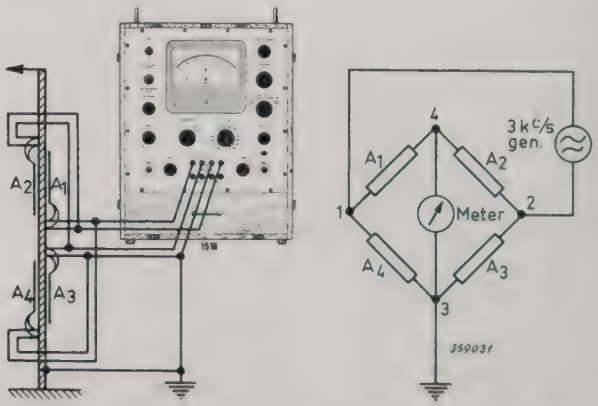

Fig. 17. Measurement of bending employing four active gages.

bridge circuits employing more than one active gage the meter reading must be multiplied by a correction factor, in this case ¼.

INSULATION RESISTANCE OF INSTALLED GAGES.

After the gages forming an installation have been mounted, a check should be made to ensure that no earth faults exist. An earthing fault of the type shown in Fig. 18 will shunt the active strain gage and reduce the accuracy of measurement. A further aspect of such a fault is that the resistance of the shunt will not remain constant. The insulation resistance ought to be better than 10^4 MΩ, this resistance can be measured with the B & K Megohmmeter Type 2423.

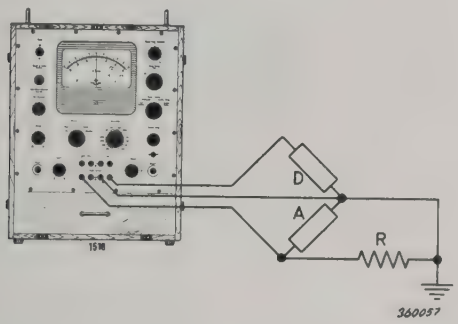

Fig. 18. Earth fault. R is equal to leak resistance.

Accessories

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Accessories

Balancing Unit Type 1530.

In all strain gage applications it is of great importance that the measurement should be carried out with the minimum possible length of wires inside the bridge circuit. It is for this reason advisable to use Balancing Units when taking measurements over considerable distances.

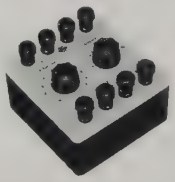


Fig. 19. Balancing Unit Type 1530.

Design. The Balancing Unit is intended for balancing of one remote measuring point and has two built-in resistors which form two of the bridge arms. One active and one dummy gage are used for tensile and compressive strain and two active gages for bending. The apparatus has self-contained R- and C-balancing and is connected to Strain Gage Apparatus Type 1516 at terminals 1, 2, 3 and 4. It is therefore possible to carry out measurements adjacent to the Strain Gage Apparatus (with strain gages connected to terminals II) and at a position some distance from the apparatus. The advantage of placing the complete bridge at the point of installation is that the resistance of connecting wires does not appear in the bridge circuit, where it would produce inaccuracies. The TERMINAL SWITCH on the Strain Gage Apparatus is used in this case to switch from one measuring point to the other.

Function. In Fig. 20 an arrangement is shown with the gages 50 metres from the instrument. The circuit is such that the resistance of the connecting wires R_{Cu1} and R_{Cu2}, appears in the bridge circuit. It must therefore be presumed that R_{Cu1} and R_{Cu2} will remain constant during measurements, however, such may not be the case. A temperature difference of as little as 1° C between two copper conductors 50 metres long and of 1 mm² cross-section will produce a resistance change of R = 3.4 milliohms. Using a 100 Ω strain gage with a gage factor of 2, the Strain Gage Apparatus would show an apparent strain of 17 μStrain, i.e. 17 % of the full-scale deflection using maximum sensitivity. This source of error may be avoided by employing a

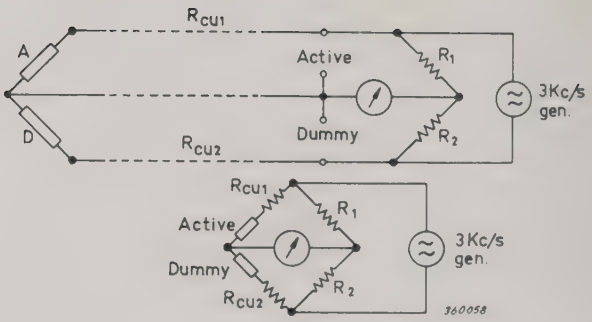


Fig. 20. Effect of long leads within a bridge circuit.

Balancing Unit adjacent to the gage installation. The circuit, Fig. 21, shows how the Balancing Unit Type 1530 is employed to bring the resistance of connecting wires outside the bridge.

If one wire is now subjected to a temperature change of 1° C the effect will be negligible, as only the bridge supply voltage will change, and then by only 0.0034 %, affecting the sensitivity by the same amount. With all measurements, however, the wire resistance should be small compared with the impedance of the strain gage used.

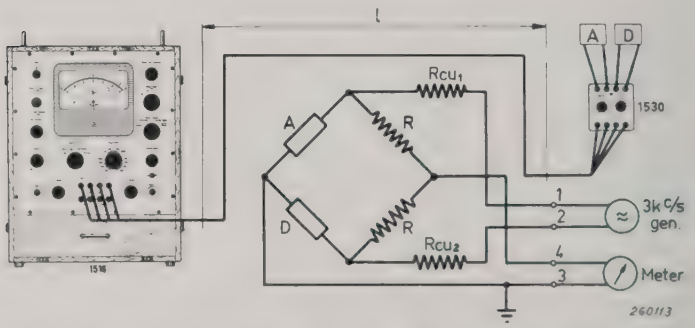


Fig. 21. Employing Balancing Unit Type 1530 in remote measurements.

Correction on Gage Factor Setting. As previously explained the GAGE FACTOR ADJUSTMENT control operates by regulating the bridge voltage. This voltage is measured at the instrument and does not take account of the voltage drop in the wires; compensation should therefore be made when long cables are being used in the circuit. The new gage factor may either

be calculated, or found by direct measurement. In the following example, only the resistance of wires 1 and 2 has been taken into account, the resistance of wires 3 and 4 is of no importance because of the relatively high input impedance of the amplifier.
The resistance of the leads is found from the formula:

$$R_{Cu} = R_{Cu1} + R_{Cu2} = \frac{0.035 \times l}{a} \Omega$$

where l is the length of cable in metres between the Strain Gage Apparatus and the Balancing Unit and a is the cross-sectional area in mm^2. The constant 0.035 is effective for copper wire (specific resistance 1.75×10^{-6} Ω cm).
If the resistance of the wire is 0.5 % or less of the gage resistance then the effect may be neglected, if above 0.5 % then a corrected gage factor should be found from the formula

$$k'' = k \frac{R}{R + R_{Cu}}$$

where k is the actual gage factor and R is the bridge resistance seen from the diagonal where the supply is applied, equal to the resistance of one arm if all arms are the same. R_{Cu} is the resistance of wires 1 and 2, and k" is the gage factor including compensation.
When using Balancing Units with built-in resistors, or the lower terminals of the Strain Gage Apparatus, the fixed bridge arms are 100 ohms each. The bridge resistance is then:

$$R = \frac{200 \times 2\, R_S}{200 + 2\, R_S}$$

where R_S is the resistance of one of the strain gages used.

Example 1.

The length of cable between Strain Gage Apparatus Type 1516 and Balancing Unit Type 1530, l = 20 metres.
The cross-sectional area of cable = 2.5 mm^2.
The resistance of one gage = 120 Ω.
Gage factor: 2.55.

$$R = \frac{200 \times 2 \times 120}{200 \times 2 \times 120} = 109\ \Omega$$

$$\text{Now } R_{Cu} = \frac{0.035 \times 20}{2.5} = 0.28\ \Omega < 0.005 \times R.$$

The wire resistance may therefore be ignored.

Example 2.

If the distance is now 200 metres the k" must be calculated because $R_{Cu} = 2.8\ \Omega$, $> 0.005 \times R$.

$$k' = 2.55 \times \frac{109}{109 + 2.8} = 2.49.$$

The value of k" can be found by measurement. Once the Strain Gage Apparatus has been adjusted in the normal manner, the 3 kHz bridge supply voltage, between terminals 1 and 2 is measured at the Strain Gage Apparatus The gage factor value is then decreased until the voltage measured at the Balancing Unit is exactly the same as that first measured at the apparatus, k" may then be read off the gage factor scale.

Balancing Unit Type 1531.

In a situation where it is required to take measurements from a number of strain gaged positions using one Strain Gage Apparatus, the Balancing Unit Type 1531 can be employed.

The unit has four independent sections, each with two built-in bridge arms and R- and C-balancing components

Fig. 22. Balancing Unit Type 1531.

The four terminals marked 1, 2, 3 and 4 are connected to the corresponding terminals of terminal set "I" on the Strain Gage Apparatus Type 1516. As the circuits should be balanced before use, the ADJUSTMENT SWITCH on Type

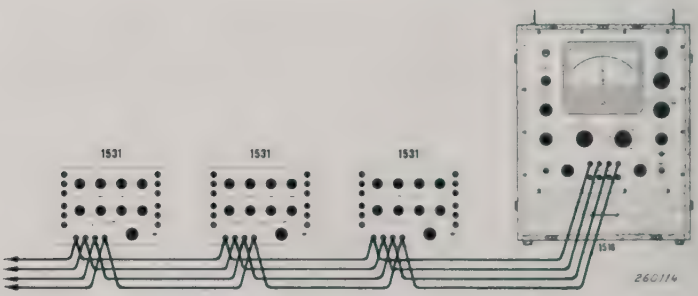


Fig. 23. Parallel connection of Balancing Units Type 1531.

1516 is set to "R-C Balance" and the BALANCE control turned to "Off" Balance is then obtained, using the balancing components in the 1531, at each of the four positions of the TERMINAL SWITCH. The ADJUSTMENT SWITCH of the 1516 is then turned to "Operation" and the measurements taken.

Any number of Type 1531 units may be connected in parallel, see Fig. 23, so that it becomes possible to select any one of a large number of measuring points at will. Two gages are used at each measuring point, one active and one dummy for tension and compression, and two active gages for bending

Variable Balancing Resistor Type 1533.

When taking measurements in the manner described in the paragraph "Recording with Cathode-Ray Oscilloscope" a distinction must be made between three different groups:—

1. Purely dynamic measurements, as shown in Fig. 25a.
2. Purely static measurements, as shown in Fig. 25b.
3. Measurements of combined static and dynamic strains, Fig. 25c.

Groups 2 and 3 are easily read, e.g. in Fig. 25c the strain amplitudes and frequency can be easily seen.

Fig. 24. Variable Balancing Resistor Type 1533.

In the case of Fig. 25d, however, analysis of the envelope can be difficult, as overmodulation is present especially when the waveform is not sinusoidal. Under conditions of overmodulation it is not possible, by observation, to deduce which deflection (peak-to-peak) is due to the compressive strain and which to the tensile. If only one bridge circuit is being investigated and connections are made to TERMINAL SET II the waveform may be studied as follows:—

The amplitude of adjacent deflections should be noted as the first step. Then, if the R-BALANCE control is turned clockwise, the deflection which increases in amplitude will be the tensile one. A further turning of the R BALANCE knob until the modulation is less than 100 % will enable the dynamic strain curve to be studied. This technique may also be employed if a number of installations are to be examined. There is, however, the great disadvantage that the balance position is lost. The Variable Balancing Resistor Type 1533

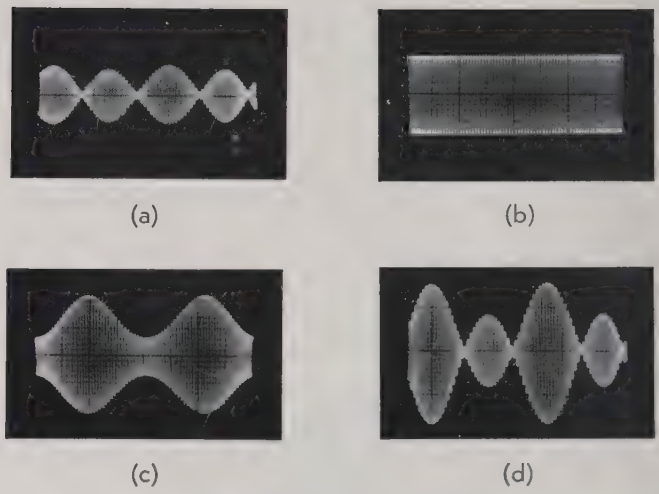


Fig. 25. Signals obtained on cathode-ray oscilloscope.
(a) Purely dynamic. (b) Purely static. (c) Combined dynamic and static.
(d) Combined dynamic and static. Overmodulation.

enables both the waveform and deflection sense to be determined, the application of the resistor being relatively simple. If TERMINAL SET II is used, the Type 1533 is connected across the dummy gage. It will, when switched in, shunt the dummy and produce an effect similar to an increase in tensile strain at the active gage. Thus the sense and form of a complex overmodulated wave may be studied by the use of the 1533 without losing the zero setting.

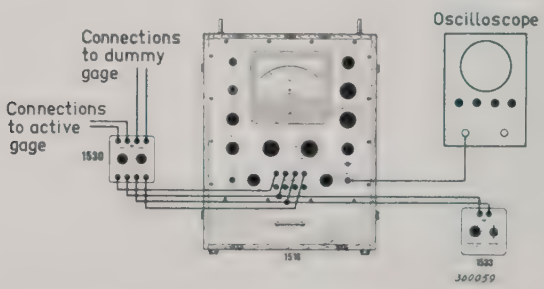


Fig. 26. Connection of Variable Balancing Resistor Type 1533 in conjunction with Balancing Unit Type 1530

If a four gage bridge is being employed, it should always be remembered, when determining the sense of the modulation envelope, that the shunting effect of the 1533 produces the equivalent effect of a compressive strain in the shunted gage.

Balancing Unit Type 1534.

By using two active and two dummy gages it is possible to determine whether pure elongation or bending is being measured. This feature is made use of in the Balancing Unit Type 1534, which has terminals for two measuring points, with one position for bending and one for elongation at each

Fig. 27. Balancing Unit Type 1534.

point. The unit has four independent sets of R- and C-Balancing components which are used to obtain balance at each measuring point both for bending and elongation.

When the TERMINAL SWITCH on the Balancing Unit is set to position "Elongation" (I or II) the strain gage bridge (TERMINAL SET I OR II) is in-

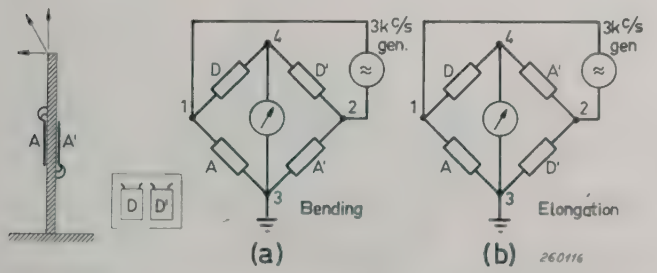


Fig. 28. Two circuit arrangements which can be obtained with the Balancing Unit Type 1534.

ternally connected in a way so that it indicates only the partial strain arising from the elongation (vide Fig. 28b), because the strain which has arisen from the bending is balanced out by the method the respective gages are lined up. By changing the TERMINAL SWITCH to position "Bending" (I or II) this identical bridge, now connected as in Fig. 28a, is only sensitive to the partial strain appearing from bending, for in this case the effect from elongation is balanced out.

The arrangement shown in Fig. 28a will give a double deflection for pure bending, while the arrangement in Fig. 28b will give a double deflection for pure elongation.

NOTE: Compressive strains and tensile strains are measured in the "Elongation" position.

Balancing Unit Type 1534 may be paralleled in the same manner as the Type 1531, allowing a large number of measuring points in the same set-up to be investigated.

DC Bridge Supply Unit Type 1535.

When taking recordings of vibration above 300 Hz, or transient conditions, the DC Bridge Supply Unit Type 1535 should be used. The resulting signal may then be observed and an oscillogram taken from a cathode-ray oscilloscope. When recording transient deformations caused by explosions or other shock conditions, the oscilloscope display may be photographed, using a synchronized time base, or the oscilloscope time base may be switched off and the film moved across the screen at some suitable speed. The input to the oscilloscope can be taken from Strain Gage Apparatus, OUTPUT I or OUTPUT II, OUTPUT II SELECTOR being in the position "Amplifier Output". A high gain oscilloscope will be required if OUTPUT I is to be used, because this output point is situated before the amplifier.

Fig. 29. DC Bridge Supply Unit Type 1535.

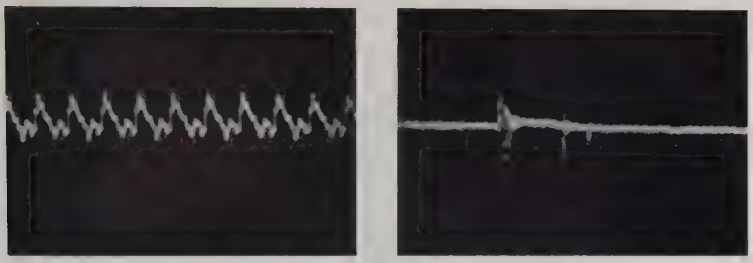


Fig. 30. Signals on a cathode-ray oscilloscope when bridge DC supplied.
(a) Repetitive dynamic signal.
(b) Transient signal.

With OUTPUT II SELECTOR switched to "Amplifier Output" the whole of the Strain Gage Apparatus' amplifier is used. The amplifier response is flat, ± 1 dB, between 20 Hz and 100 kHz, with an amplification of about 80 dB and the output impedance is approximately 600 Ω.

Function. Figs. 31, 32 and 33 show schematically the connections in the DC Bridge Supply Unit for various positions of the ADJUSTMENT SWITCH.

"Reference Adjust". The circuit is shown in Fig. 31, and may be seen to comprise of a bridge of four 100 Ω resistors and an indicating meter. The

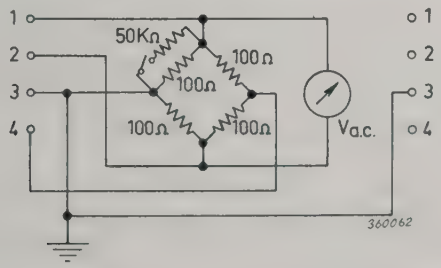


Fig. 31. Circuit of DC Bridge Supply Unit when ADJUSTMENT SWITCH is in position "Reference Adjust.".

indicating meter of the 1535 measures the AC voltage applied to this 100 Ω bridge and the voltage should be adjusted at the 1516 until the needle corresponds with the red line on the meter scale; at this point the 3 kHz

bridge voltage is 3 volts RMS. When the circuit is perfectly balanced a zero line as in Fig. 35a is obtained.

"Ref. 1000 μStrain". In this position one bridge arm is shunted by a 50 kΩ resistor, shown in Fig. 33, the effect of this shunt is to produce a bridge signal corresponding to 1000 μStrain, measured with a strain gage having a gage factor of 2. The signal shown in Fig. 35b will be obtained, the amplitude of which, may be suitably adjusted as explained in "Operation of Type 1535".

"Operation AC". In this position there is a through connection from one set of terminals to the other (Fig. 32), the instrument is thus effectively switched out and measurement can be made with the 1516 in the normal way. The position is used for R- and C-balancing of the installation, and for measuring with the 3 kHz bridge voltage. The facility of being able to switch from DC to AC supply is very useful if, for example, it is necessary to know

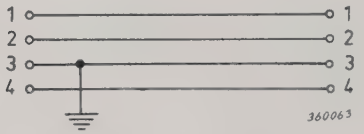


Fig. 32. Circuit of DC Bridge Supply Unit when ADJUSTMENT SWITCH is in position "Operation AC".

the steady strain condition before and after a mechanical shock. Of course, the use of the two types of supply will mean that initially the instrumentation must be adjusted for both. The DC adjustment should be made as previously described. The adjustment for AC operation is carried out by obtaining the appropriate gage factor on the 1516 and then comparing a meter deflection on the Strain Gage Apparatus (obtained by shifting the R-BALANCE a definite amount), to the amplitude of signal obtained on the oscilloscope whereby a scaling factor is thus obtained.

"Operation DC". Fig. 33. The gage installation is now fed with DC from three dry batteries. The bridge voltage is regulated by the potentiometer GAGE FACTOR DC and measured on the built-in instrument, which is so calibrated that the appropriate bridge voltage may be obtained for the particular gage factor considered.

The DC voltage, corresponding to a gage factor of 2, should be $3 \times \sqrt{2}$ volts because the adjustment mentioned under *Ref. 1000 uStrain* is made with an AC voltage of 3 volts RMS. Obviously factors of 3.16 and 10 become involved if the bridge voltage is reduced to the nominal 1 volt or 0.3 volt; this point is explained under "Operation of Type 1535".

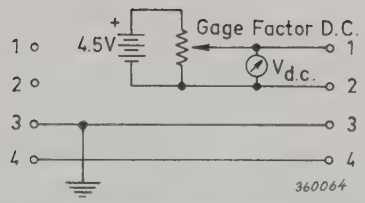


Fig. 33. Circuit of DC Bridge Supply Unit when ADJUSTMENT SWITCH is in position "Operation DC".

Connections. When the Supply Unit is employed as shown in Fig. 34, it is advisable to use screened connecting cables as the system is not insensitive to hum which is the case when the 3 kHz carrier and the tuned output stage of the strain Gage Apparatus is used.

A 2-core screened cable should be used for the bridge supply connected at 1 and 2, and a single-core screened cable used for the meter input. The screens should be joined and earthed at terminal 3, the member being strain gaged should also be connected electrically to terminal 3 which is made the common earthing point.

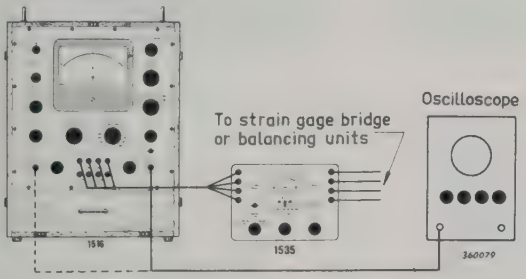


Fig. 34. Application of DC Bridge Supply Unit.

Mention should be made, that in some cases the best result is obtained if the instrumentation is earthed at the cathode-ray oscilloscope instead of at the terminal 3 on the 1516.

OPERATION OF TYPE 1535

Connections made according to Fig. 34 (refer also to the previous text).

1. ADJUSTMENT SWITCH of 1516 on "Zero".
2. Zero position of meter adjusted with ZERO ADJUSTMENT potentiometer.

3. ADJUSTMENT SWITCH of 1516 on "Operation".
   TERMINAL SWITCH of 1516 on "I".
   OUTPUT II SELECTOR of 1516 on "Amplifier Output".
   BRIDGE VOLTAGE of 1516 on 3 Volts.
   ADJUSTMENT SWITCH of 1535 on "Ref. Adjust.".
4. GAGE FACTOR ADJUSTMENT control of 1516 set to that the 1535 meter pointer is on the red mark.
5. R- and C-balancing components in 1516 used to obtain balance. Balance conditions observed on oscilloscope connected to OUTPUT II. (Fig. 35a).
6. RANGE μSTRAIN of 1516 set to 1000 μStrain at 3 V.
7. ADJUSTMENT SWITCH of 1535 to "Ref. 1000 μStrain". The deflection on the oscilloscope now corresponds to 1000 μStrain, and the oscilloscope amplifier gain is adjusted so that a suitable deflection is obtained. (Fig. 35b).

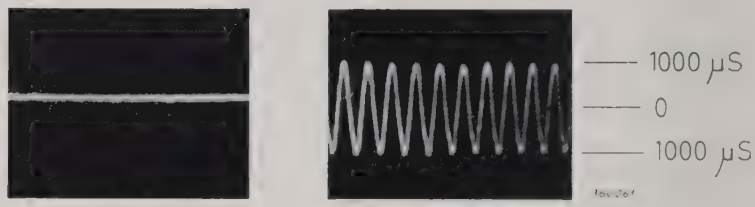


Fig. 35. Adjustment by cathode-ray oscilloscope.
(a) Zero line.
(b) Reference signal.

8. ADJUSTMENT SWITCH of 1535 set to "Operation DC".
9. BRIDGE VOLTAGE DC on 1535 turned to the voltage to be used during the measurement.
10. GAGE FACTOR DC adjusted on 1535 until the meter reads the appropriate gage factor.
11. The internal balancing controls of the 1516 are now switched out of circuit, BALANCE to "Off". The 1535 ADJUSTMENT SWITCH is turned to "Operation AC". The balancing controls in the accessories 1530, 1531, 1534, 1542 or 1543 are now used to achieve balanced conditions once again. The oscilloscope is again used as the zero indicating instrument.
12. The ADJUSTMENT SWITCH on the 1535 is turned to "Operation DC". The BRIDGE VOLTAGE switch on the 1516 is turned to "Off". The measurements may now be taken.

NOTE: The reference deflection in point 7 is valid only if the DC bridge voltage is 3 volts. If it is necessary to reduce the nominal bridge voltage to 1 volt or 0.3 volt then the gain of the oscilloscope must be

increased by 10 dB or 20 dB respectively. Alternatively the measured results must be multiplied by $\sqrt{10}$ or 10 respectively. Account must also be taken of changes in the RANGE μSTRAIN switch position.

Low-Pass Filter Type 1538.

The rectified voltage from the meter rectifier in the 1516, which is normally fed to the meter, is also fed to OUTPUT II when the OUTPUT II SELECTOR switch is in the position "Rectifier Output"

Fig. 36. Low-Pass Filter Type 1538.

This voltage is rectified but unsmoothed, i.e. there is a superimposed voltage at 3 kHz. This unsmoothed voltage has no effect on the meter deflection, but it makes the reading of an oscilloscope or oscillogram difficult. A Low-Pass Filter Type 1538 may be inserted to overcome this difficulty, the frequency range is 0—100 Hz.

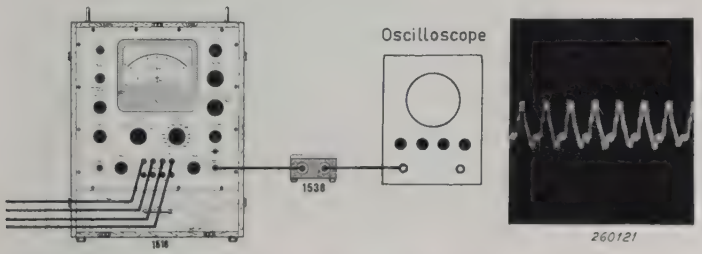


Fig. 37. Low-Pass Filter in measuring arrangement and typical resultant wave form of a dynamic strain.

Automatic Selector Type 1542 and Twenty-Point Panel Type 1543.

When the Automatic Selector Type 1542 and one or two Twenty-Point Panels Type 1543 are combined with the Strain Gage Apparatus Type 1516, an equipment for multi-point strain gage measurements is obtained. The combination allows a maximum of 50 measuring points to be successively

scanned. When 10—30 measuring points are desired, one Twenty-Point Panel should be added to the Automatic Selector, and for more than 30 bridges two Twenty-Point Panels have to be added.

AUTOMATIC SELECTOR TYPE 1542.

The Automatic Selector contains a 50-Position Switch and terminals for connection of 10 full or half strain gage bridges, as well as individual R and C-balancing components.

Fig. 38. Automatic Selector Type 1542.

The switch can be operated manually, remotely, or automatically by means of a built-in multivibrator device. The time between each switching event can be selected as 0.5—1—2 or 4 secs. In addition, the apparatus is provided with means of fast return (approximately 0.1 sec. between each switching) through unused points of the 50-Position Switch, thus the time interval of non-measurement is very small. The actual position of the 50-Position Switch can be read on a large illuminated scale which is divided into 5 sections, A, B, C, D, and E, each containing 10 steps.

When the B & K Level Recorder Type 2305 is connected to the measuring arrangement, the strain from a preselected number of measuring points can be registered automatically on recording paper. To accomplish this the Automatic Selector can either be controlled by its own multivibrator device or remotely by a switch in the Level Recorder.

DESCRIPTION

From the block diagram shown in Fig. 39 the working principle of the Selector is seen, and for the following explanations reference should be made to this diagram.

Input Circuit. The full or half strain gage bridges have to be connected to the 10 sets of terminals which are situated on the front panel and are permanently connected to section A of the 50-Position Switch.
Bridge balancing components, consisting of a variable condenser and a wire-wound potentiometer, are individually allotted for every terminal set. The circuit is in principle the same as for the Strain Gage Apparatus, except for the BALANCE potentiometer, which is omitted (Refer also Fig. 5 page 11). The potentiometers are of the 10-turn type which ensures a very high ohmic resolution, therefore giving quick and easy balancing even with a strain gage of a high resistance.

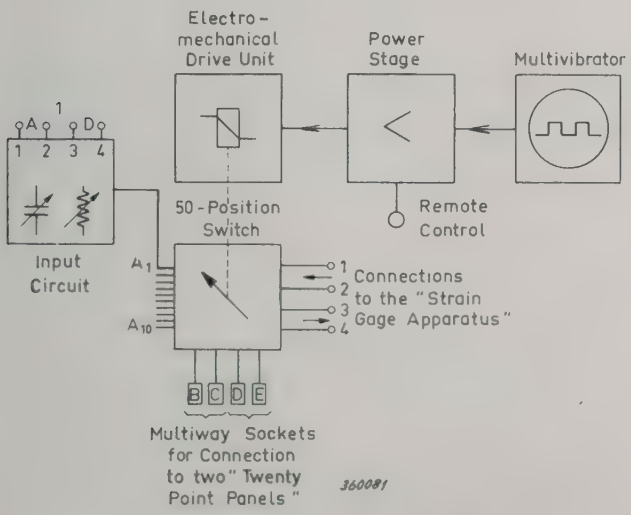


Fig. 39. Block diagram of Type 1542.

Half or Full Bridges. As previously mentioned, the Selector can be employed for connection to half as well as full strain gage bridges. When half bridges are used the other half of the bridge is substituted by two wire-wound highly stable precision resistors within the Selector. They are fundamentally incorporated as in the Strain Gage Apparatus, see therefore Fig. 5 on page 11. The two configurations of the bridge circuit can be lined up by the positioning of shorting links in a specified order on the back of the equipment. Vide Fig. 41. The links are fixed by screws. Under Operation page 53 it is shown how the links should be placed in order to obtain the desired configuration for the equipment.

50-Position Switch. The switch is of the rotary type, contains 50 positions and consists of 3 wafers. To obtain a reliable contact combined with a long life, the contact points are plated with rhodium. The switch can be operated by hand or by a built-in electromechanical drive unit which can be driven from the included multivibrator device, or remotely controlled by an external switch.

Multivibrator and Power Stage. The device consists of a free-running multivibrator and a power stage. The whole device is equipped with transistors power supplied from a rectifier. The frequency of the multivibrator can be selected by the switch AUTOMATIC SWITCHING which offers four values of time intervals between switching of 0.5, 1, 2, or 4 secs. The pulse for operating the electromechanical drive unit lasts approximately 50 msec. for all positions of AUTOMATIC SWITCHING, thus giving a short shift-time compared to the measuring intervals.

Scanning and Fast Return Arrangement. By means of two cam discs mounted on the shaft of the 50-Position Switch, and a relay circuit containing two relays, an arbitrary number between 1 and 50 of the measuring points starting at point A1 can be automatically scanned in steps. Thereafter the switch runs fast through the remaining positions until it regains position A1. In the fast running state the time interval between switching is lowered to approximately 0.1 sec. When position A1 is reached the sequence is continued. For pre-setting the measuring and return range, reference should be made to Operation, p. 54.

By a switch, FAST RETURN, situated on the rear of the equipment, the fast return arrangement can be placed out of function ("Off"), i.e. the 50-Position Switch will scan the whole cycle with the time interval selected by AUTOMATIC SWITCHING. It is important that the fast return should be set out of operation when all 50 measuring positions are employed, otherwise position 50 will not be measured. The scanning within the measuring range can be immediately stopped by setting the switch FUNCTION SELECTOR to position "Remote Control". When the switch is set in this position, during the fast return the scanning will cease only when the 50-Position Switch reaches the position A1.

Marking. A special arrangement enables external marking of that section of the 50-Position Switch which is used for measurements. The arrangement consists of bridging two terminals in the REMOTE CONTROL jack during fast return of the switch. This can be utilised, for instance, to give information on the recording paper when the measuring results are registered by a B & K Level Recorder Type 2305. Vide Fig. 51 top, where the marking line created by the Recorder's Event-Marker is shown.

Short-Circuiting of Indicating Instrument Input. During switching over from one measuring point to another the connections to the indicating system on the Strain Gage Apparatus are short-circuited. By this means two facilities are gained. Firstly, a clear indication is given when the following measuring point is switched in, as the indicating meter on the Strain Gage Apparatus or another indicating instrument used in conjunction with the Strain Gage Apparatus will give a deflection towards zero. In Fig. 51 this effect can be seen on a recording made by the Level Recorder. Secondly electrical noise which occurs in the switching moment will not be indicated. During the fast return of the 50-Position Switch (i.e. returning to position A1) the same short-circuiting action is performed through the whole selected range. By this method a check on the zero balance of the measuring equipment can be made for each revolution of the switch.

It should be noted that the mentioned short-circuiting does not take place when the 50-Position Switch is operated by hand. Further, when used in this condition the apparatus need not be power supplied.

Remote Control. The switching of the Selector can be remotely controlled by a single-poled switch. In this condition the fast return facility is also provided. The connections to be made to the REMOTE CONTROL jack can be seen in Fig. 47. The 50-Position Switch is operated when the terminals 1 and 2 are bridged. The bridging should last for at least 50 msec.

Power Supply. The Power supply for the Selector can be either 100, 115, 127, 150, 220 or 240 volts AC with a frequency between 40 and 400 Hz. Line voltage fluctuations should be kept to within $\pm$ 10 % of the set voltage value. The adjustment to one of the six voltages is carried out by a voltage selector on the rear of the equipment. The fuse, which is in circuit with the primary side of the power transformer should first be removed before the inner part of the combined voltage selector and fuse holder can be turned to the desired value. See also Fig. 41.

Screw-Driver Adjustment. The knobs on all the R and C balancing controls can be removed, allowing access to a slot in the end of all the control shafts In this manner the balancing controls can be screwdriver operated if desired

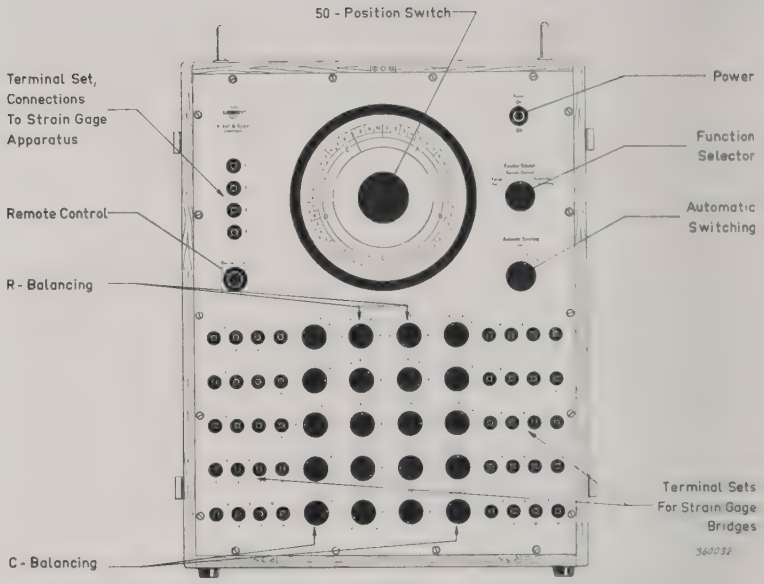


Fig. 40. Front plate of Type 1542.

IDENTIFICATION OF CONTROL KNOBS AND TERMINALS etc.

FRONT PLATE (Refer Fig. 40).

"1", "2", "3", and "4" Terminals (upper left): Should be connected to the corresponding terminals on the Strain Gage Apparatus.

"Remote Control": Pins 1—2. For remote control of the 50-Position Switch. When the pins are bridged the Switch will move but one step.
Pins 5—6. Bridging of the two pins is achieved when the 50-Position Switch passes through the preselected fast return range and is cancelled again on reaching the position A1.

"R1", "R2", "R3" ... "R10": R-balancing 10 turn-potentiometers for the terminal set "1", "2", "3" ... "10" respectively.

"C1", "C2", "C3" ... "C10": C-balancing condensers for the terminal set "1", "2", "3" .. "10" respectively.

"1", "2", "3" ... "10": For connection of up to 10 full, or half, strain gage bridges. Each set is marked with an A (active gage) and D (dummy gage). These letters refer to the half bridge configuration. The terminal sets are lined up with the positions A1, A2, A3 ... A10 respectively on the 50-Position Switch.

50-Position Switch: For the successive connection of up to 50 bridges to the Strain Gage Apparatus.

"Power": For switching on and off the power supply of the apparatus. When in the "On" position the switch scale will be illuminated.

"Function Selector":
"Range Adjustment" position is used for setting the desired successive number of measuring points.
"Remote Control" position is selected when it is desired to remote control the 50-Position Switch. Additionally, if set to this position the Automatic Switching can be stopped.
"Automatic Switching" position for the automatic switching of the 50-Position Switch.

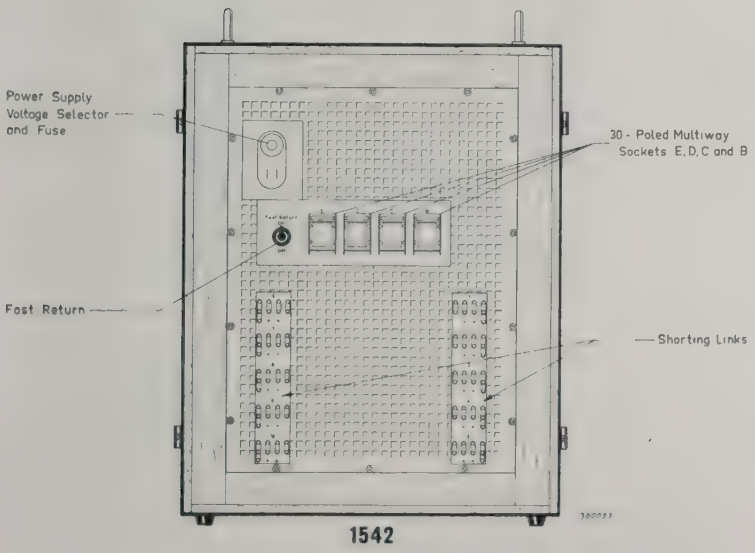


Fig. 41. Rear view of Type 1542.

"Automatic Switching": "0.5", "1", "2" or "4" sec. can be selected as the time interval between each switching step, when FUNCTION SELECTOR is in position "Automatic Switching".

TWENTY-POINT PANEL TYPE 1543

The Twenty-Point Panel is designed as a supplement to the Automatic Selector Type 1542. By employing two Panels in connection with the Automatic Selector, all measuring positions on the Selector can be utilised.

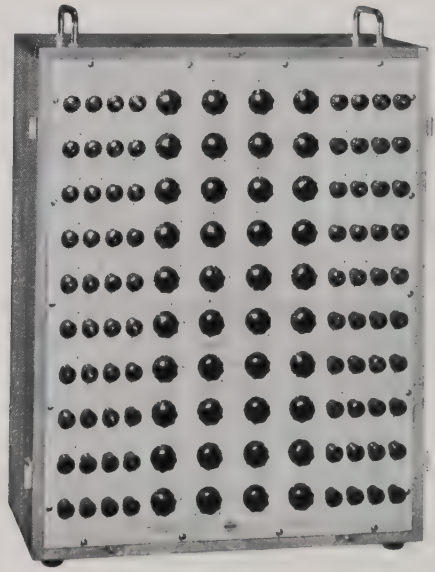


Fig. 42. Twenty-Point Panel Type 1543.

The Twenty-Point Panel consists of two sections, each containing 10 terminal sets for connection of either full, or half, strain gage bridges. For each of the 20 terminal sets individual R and C balancing components are supplied. All 20 terminal sets are connected to two 30-poled multiway sockets, from which further connections can be made to the respective multiway sockets on the Automatic Selector by means of two 30-cored cables AO 0030 of approximately 1 meter length. The cables are supplied with the corresponding multiplugs.

The R and C balancing components and their placing with regard to the 2×10 terminal sets are identical to that of the Automatic Selector. In addition, the circuit for lining up to full or half bridges and the positioning of the shorting links are also similar to that of the Selector. For these items reference should therefore be made to the respective paragraphs in the description of the Automatic Selector Type 1542.

OPERATION
(Automatic Selector and Twenty-Point Panel).

GENERAL

Setting to Proper Power Supply Voltage.

Check on the Automatic Selector that the power supply voltage selector is set to the proper voltage. If not, remove the fuse (see also Fig. 41) and turn the middle portion of the combined fuse holder and selector until the white mark rests opposite the proper voltage. Replace the fuse and switch POWER to "On". The scale should immediately be illuminated, showing that the apparatus is ready to be set-up.

Lining up to Full or Half Strain Gage Bridges.

In Fig. 43 is shown how the shorting links should be placed on the Automatic Selector and Twenty-Point Panel to obtain the desired configuration. The links are viewed from the rear of the equipment.

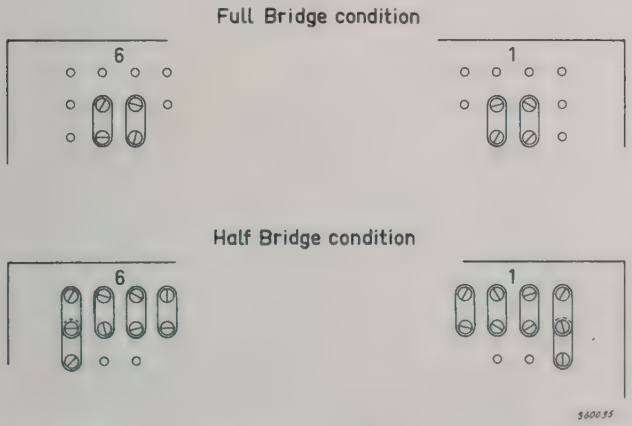


Fig. 43. Lining up for connection of half or full bridges. The two upper sections are shown.

NOTE: When lining up for full bridges it is recommended to place the surplus links on top of these shown, and further to place the superfluous screws in the unused holes. By this means all the screws and links are always at hand. In fixing the links, the screws should be sufficiently tightened to avoid doubtful contact.

ADJUSTMENTS AND CONNECTIONS

A. 10 MEASURING POINTS OR LESS

In this case the Automatic Selector combined with the Strain Gage Apparatus will suffice as the Selector contains terminal sets for a maximum of 10 measuring points.

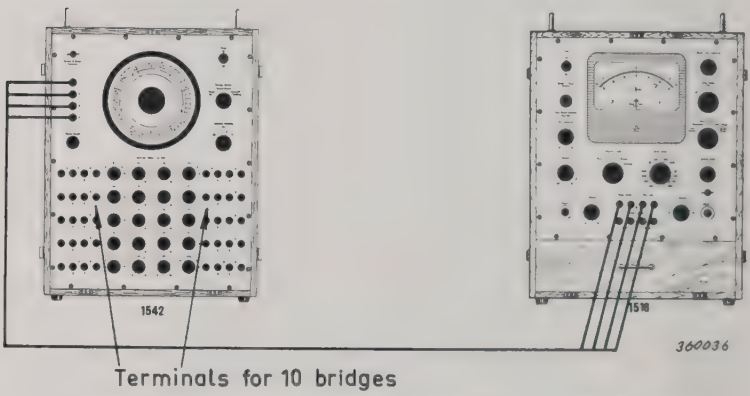


Fig. 44. Measuring arrangement for up to 10 measuring points.

I. Automatic Switching.

1. Connect the Selector to the Strain Gage Apparatus as shown in Fig. 44. For the type of wires and method of lining up, reference should be made to the Strain Gage Apparatus, page 26.
2. Operate Automatic Selector as follows:—
   (a) Set FUNCTION SELECTOR to "Range Adj.".
   (b) FAST RETURN (situated on the rear of the apparatus) to "On".
   (c) Connect the desired numbers of strain gage bridges to the terminal sets on the Selector in numerical sequence, beginning on set "1".
   Concerning types of bridges, reference should be made to the figures on page 29 and 30.

(d) Turn the 50-Position Switch manually until a small click is heard and the switch feels loaded.

(e) Turn the 50-Position Switch to a position one number higher than the number of bridges which are to be measured.

Example:—
7 bridges connected.
Turn the Switch to position A8.

(f) Set FUNCTION SELECTOR to "Remote Control", whereafter the 50-Position Switch runs fast, but stops at position A1.

3. Adjust the Strain Gage Apparatus Type 1516 (Refer page 21) and balance the connected strain gage bridges. During the balancing procedure the various bridges are selected manually by the 50-Position Switch.
4. Select the desired measuring time interval by means of the knob marked AUTOMATIC SWITCHING.
5. Start the automatic scan by setting the FUNCTION SELECTOR switch to position "Automatic Switching".

NOTE: The scanning of the measuring points can be ceased by setting FUNCTION SELECTOR to "Remote Control".

II. Automatic Recording. (Switching controlled by the Selector).
By connecting the B & K Level Recorder Type 2305 to the equipment in Fig. 44 the measuring results can be recorded on paper. The

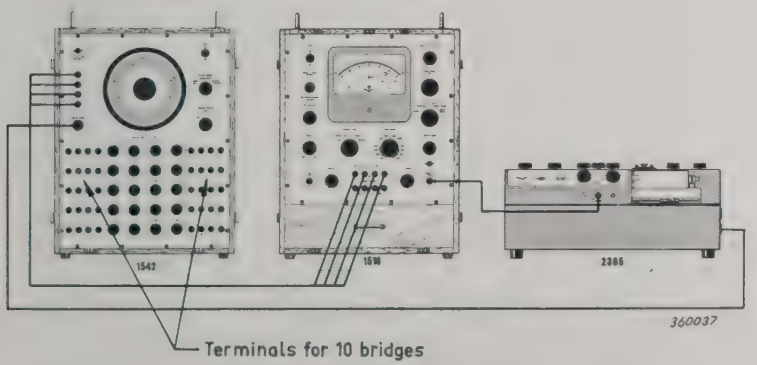


Fig. 45. Measuring set-up for recording.

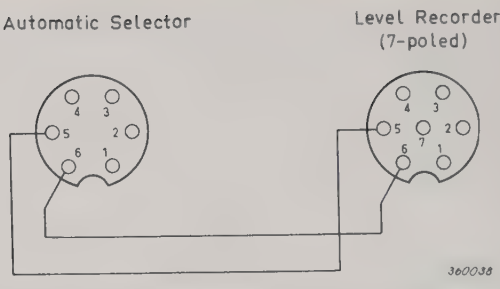


Fig. 46. Connections between REMOTE CONTROL's of Type 1542 and Type 2305 for identification of position "A1". (Jacks viewed externally).

measurement takes place, runs automatically off, and is repeated after each scanning cycle.

1. Connect the instruments as shown in Fig. 45.
2. Adjust the combined Strain Gage Apparatus and Level Recorder as outlined in part "Recording with Level Recorder Type 2305", page 23.
3. Connect the REMOTE CONTROL jack on the Automatic Selector (6-poled) to the REMOTE CONTROL jack on the Level Recorder (7-poled) as shown in Fig. 46. This connection ensures an indication of th ebeginning of each measuring cycle (A1) by the Event-Marker of the Level Recorder, see Fig. 51 top.

III. Remote Control.

By means of a single-poled contact the switching action of the Automatic Selector can be controlled.

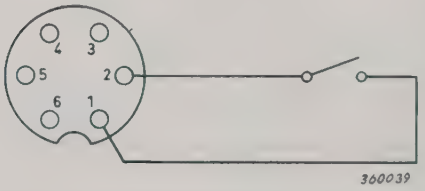


Fig. 47. Connections to REMOTE CONTROL of Type 1542 for remote control. (Jack viewed externally).

1. Adjust and line up the instruments as described in paragraph "Automatic Switching" page 54, item 1 to 3 inclusive.

2. Connect the REMOTE CONTROL socket as indicated in Fig. 47.
3. The equipment is now ready for use. Each time the contact shown in Fig. 47 is closed the 50-Position Switch moves one step. When the last measuring point has been tested a new closing and then opening of the control contact causes the "fast return" to operate, and the Switch moves swiftly to position A1.

IV. Automatic Recording. (Switching remotely controlled by Level Recorder).

To remote control the 50-Position Switch on the Automatic Selector from the B & K Level Recorder Type 2305, proceed as follows:—

1. Connect the Level Recorder to the equipment and adjust as described in the previous paragraph A II, "Automatic Recording".
2. Adjustment and lining up of the Selector is performed as laid down in paragraph A I, item 1—3 inclusive.
3. Further connection between the REMOTE CONTROL sockets of the two apparatus have to be accomplished as sketched in Fig. 48.
4. The cam disc with the short cam is mounted on "Drive Shaft II" of the Level Recorder.

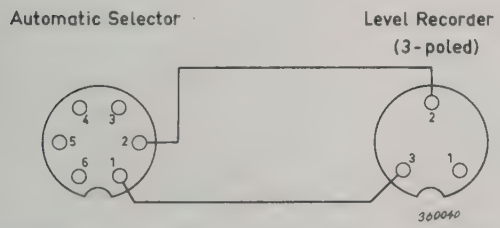


Fig. 48. Connections between REMOTE CONTROL's of Type 1542 and Type 2305 when switching controlled by the Level Recorder. (Jacks viewed externally).

5. When a suitable "Paper Speed" and "Drive Shaft Speed" have been chosen, the recording can be started. By choosing the value for the "Drive Shaft Speed" reference should be made to the example in "Switching Controlled by the Level Recorder", p. 61.
6. The scanning is automatically repeated for every complete cycle of the 50-Position Switch, until the Level Recorder is stopped

B. 11 TO 50 MEASURING POINTS

In measurements where more than 10 bridges are to be tested, one, or if necessary two, of the Twenty-Point Panels Type 1543 should be added to the combined Strain Gage Apparatus and Automatic Selector

I. Automatic Switching, Recording and Remote Control.

Fig. 49 illustrates a measuring arrangement for testing of 31 to 50 bridges. In the figure the Type 1542 covers the first 10 bridges (Section "A" on the 50-Position Switch), Type 1543 "I" the next 20.

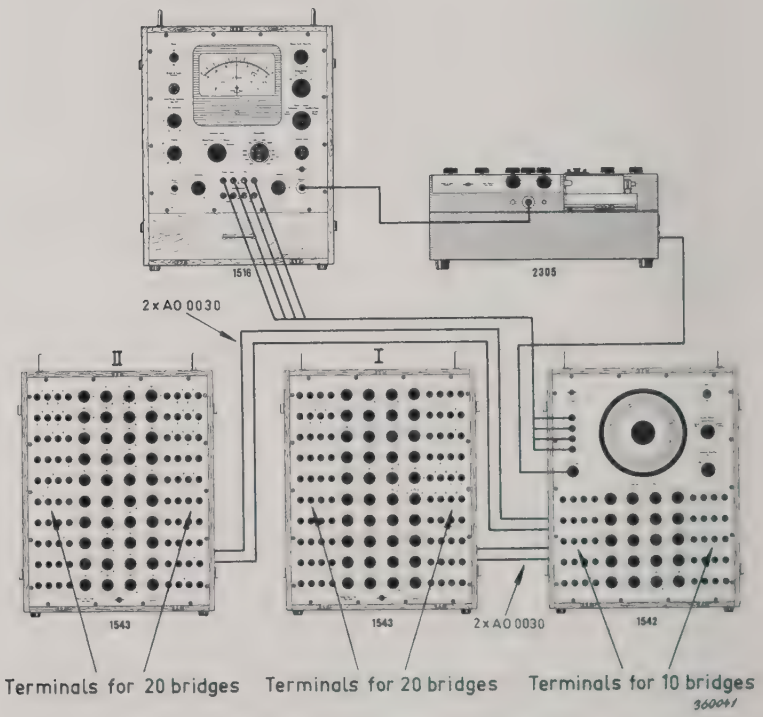


Fig. 49. Equipment for scanning of up to 50 bridges.

(Section "B" and "C") and Type 1543 "II" the rest (Section "D" and "E"). Type 1543 "I" is therefore connected to the multiway sockets "B" and "C" on the rear of Type 1542 by means of two 30-cored

cables AO 0030. Type 1543 "II" is similarly connected to the multi-way sockets "D" and "E".

The Level Recorder Type 2305 for registering the result is also shown in the figure.

The lining up, adjustments, recording and control methods are as described in paragraph A "10 Measuring Points or Less", p. 54.

EXAMPLES OF RECORDING AND MEASUREMENTS

In the following paragraphs are given some examples of the measuring methods for multi strain gage measurements and their associated recordings.

Automatic Switching.

Measurements were firstly carried out on 30 half bridges and afterwards on seven of the same type. In the first case the equipment was connected as

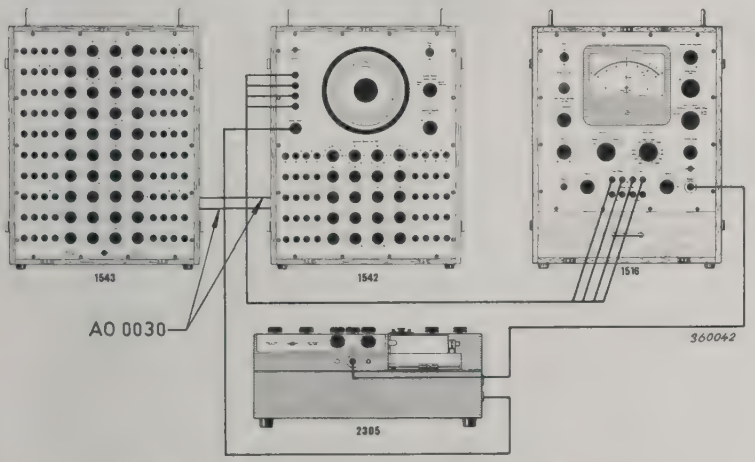


Fig. 50. Measuring arrangement for checking of 30 bridges.

in Fig. 50, and in the second case, as in Fig. 45, FUNCTION SELECTOR of the Automatic Selector was set to "1 sec.". Fig. 51 presents the recording on the 30 bridges. It is seen that an easy evaluation of the strain in each of the 30 bridge points is achieved. The deflections towards the zero line at the point of switching are due to the short-circuiting of the indicator input of the Strain Gage Apparatus. This property ensures clear separation of successive

deflections of the same value. On top of the recording is seen the marking made by the EVENT-MARKER. One mark is given when the first measuring

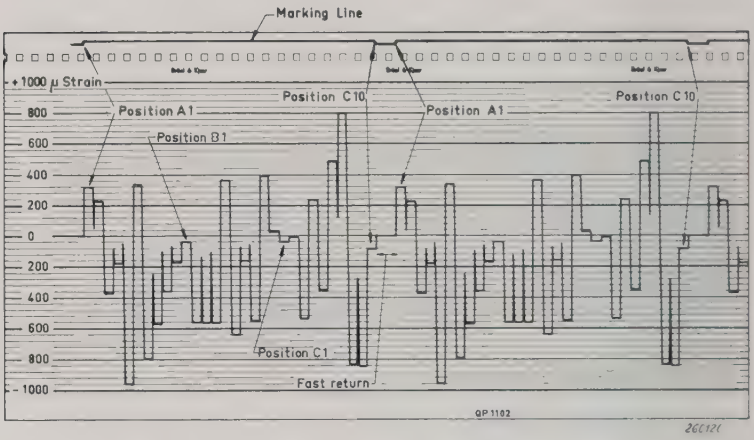


Fig. 51. Recording of strain in 30 different points.

point is switched in (A1), and another when the last is switched out (in this case C10), here the fast return starts.

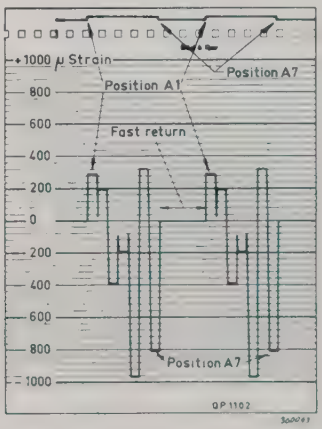


Fig. 52. Recording of strain in 7 different points

When measuring on 7 bridges only, the Twenty-Point Panel Type 1543 can be omitted. Fig. 52 shows the recording. It should be noted how little space the fast return range (point A8 to E10) occupies on the recording as compared to a whole cycle.

Switching Controlled by the Level Recorder.

Measurements were carried out on 27 bridges. The measuring set-up was as in Fig. 50. In Fig. 53 can be seen a recording made by this method.

It is recommended to choose the time interval between each switching in the measuring range to be longer than the time it takes to quickly return from the last measuring point, otherwise the measurement position A1 can be lost. In the example shown the DRIVE SHAFT SPEED of the Level Recorder has been 12 r.p.m., i.e. the time interval between switching is thus:—

$$\frac{60}{12} = 5 \text{ secs.}$$

As the fast return range takes approximately o.1 sec. per step, the range is in this case stepped through (before stopping at A1) in:—

$$23 \times \text{o.1} = 2.3 \text{ sec.}$$

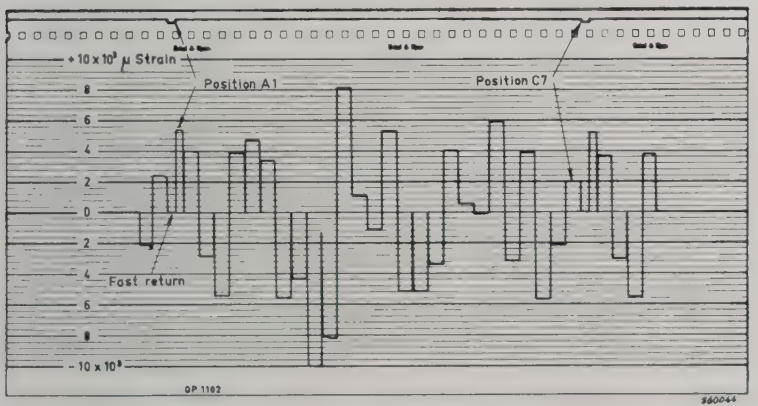


Fig. 53. Recorded result of measurement at 27 points. Switching controlled by the Level Recorder.

The measuring time on point A1 will thus be reduced to:-

$$5 - 2.3 = 2.7 \text{ sec.}$$

which can be seen from the recording, Fig. 53.

In Fig. 54 is shown a recording of measurements carried out over a longer period of time. When the Level Recorder PAPER SPEED is known, in this example 0.1 mm/sec., the paper can be calibrated in time, as illustrated by the recording. The number of measuring points in this case were seven and the DRIVE SHAFT SPEED was 3.6 mm/sec.

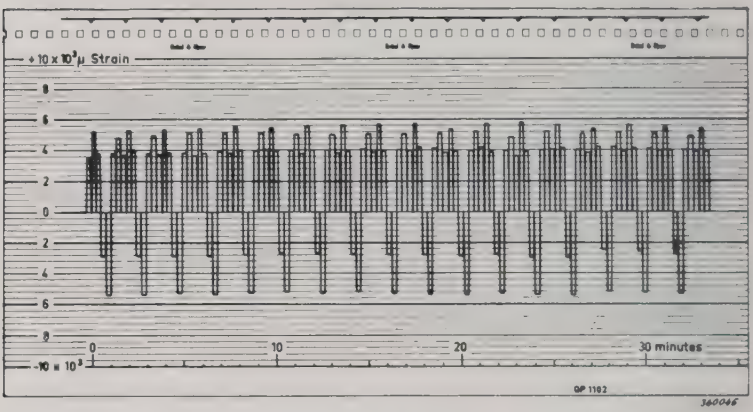


Fig. 54. Recording over a lengthy period at 7 points. Switching controlled by the Level Recorder.

Multipoint Measurements with one Dummy Gage.

In multipoint measurements it is advantageous, when possible, to employ only one dummy gage against all the active gages, as this demands a less expensive and more simple method of lining up. For example, the principle can be utilized in model experiments where the model is exposed to constant temperature.

The B & K multipoint measuring equipment may, under special circumstances, be employed for this type of measurements. However, as the contacts of the 50-Position Switch in the Automatic Selector in this case is within the bridge circuit, any alteration in contact resistance of this may effect the measurements. In addition, the contact resistance in the 30-poled multiway sockets may also experience some perceptible alteration with time, if the contacts are not kept clean. The equipment should under these circumstances therefore only be used in dynamic and static measurements in cases where a relatively low sensitivity is required.

The integrating parts of the equipment are connected and lined up as described under part Operation, page 53, except for the lining up of the strain gages, which is carried out with the following alterations:

After the equipment is set up for half bridge measurements, the active gages are connected in the normal way, the D (dummy) terminal sets being left open.
The single dummy gage is then connected between terminal "2" and "3" (Terminal Set "I") of the Strain Gage Apparatus.
With these conditions satisfied the measurements can now commence.

Applications

Matching Strain Gages 65
Measurement of Extension 65
Measurement of Bending Stresses 67
Measurement of Torsion 68
Spectrum Analysing of Dynamic Measurements 72
Weighing by the Strain Gage Apparatus using Unbonded Strain Gages 74
Measurement of Fluid Levels and Wave Heights 74

Applications

Matching Strain Gages.

When a number of gages are to be installed it is advisable to match the gages forming each bridge, or half bridge, as closely as possible. The subsequent balancing will be much easier, and it will not be necessary to externally shunt any of the strain gage arms. Shunting an active gage with a resistance also decreases the measuring accuracy. Refer Appendix, page 77.

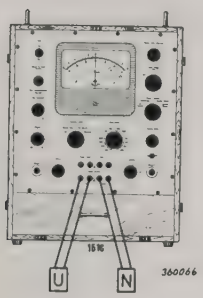


Fig. 55. Matching of strain gages employing Strain Gage Apparatus.

The terminal set "II" is used when matching strain gages. Two strain gages are connected to the terminals and the bridge is balanced. The gage factor reading is set to 2. The gage connected to the DUMMY terminals will be used as a "normal" strain gage during the measurements, and the gages to be matched will be connected to the ACTIVE terminals. Fig. 55. The subsequent deviation, in ohms, from the resistance of the gage first connected to the ACTIVE terminals, is $2 \times 10^{-5}\ \alpha$, where α is the deflection in αStrain on the apparatus.

Measurement of Extension.

To obtain the basic "stress-strain" curve for a material, a standard test bar is fastened in a tensile test machine and the strain noted on an extensionmeter.

as the load is gradually increased. The slope of the stress-strain curve over the linear portion is

$$\frac{\text{tensile stress.}}{\text{tensile strain.}} \qquad \frac{\text{kg/cm}^2}{\text{dimensionless}}$$

and the relationship is called Young's Modulus, or the Modulus of Elasticity, denoted by E,

$$\text{thus } E = \frac{\text{Stress}}{\text{Strain}} = \frac{p}{e} = \text{kg/cm.}^2.$$

The relationship between e and p will be linear up to some stress intensity p_1, the "elastic limit". For loads above p_1 the relationship between p and e is no longer constant; if loaded above p_1 a permanent extension will remain in a specimen after the load is removed.

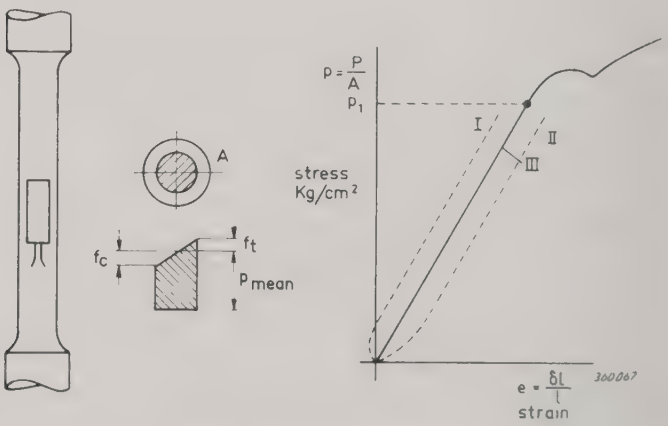


Fig. 56. Stress-strain relationship.

If strain gages are to be used to obtain the stress/strain relationship it will be necessary to affix to the specimen two gages positioned diametrically opposite each other, and connected as in Fig. 28b. It is important to adopt this procedure in order to compensate the initial bending introduced in the tensile specimen when loaded in the testing machine. Fig. 56 shows the stress distribution across the specimen, and it will be seen that the stress varies from $p_{mean} + f_t$ to $p_{mean} - f_c$, where f_t and f_c are the tensile and compressive stresses respectively, produced at the surface layers by the bending. In the graph, curve I shows the stress/strain relationship at the surface by the one gage and curve II the relationship by the other. Due to the bending-compensating bridge configuration, the reading on the Strain Gage Apparatus will be as illustrated by curve III.

Measurement of Bending Stresses.

Fig. 57 shows a classical bending example, a beam of span l_2 is placed symmetrically over supports, the two loads W, are equal, as are their distances from the supports, thus the reactions R_1 and R_2 are equal. If the beam has a constant cross-sectional area, which is symmetrical about the neutral axis, it will have a constant Moment of Resistance and a constant Bending Moment between R_1 and R_2. Under static conditions of equilibrium the Bending Moment and Moment of Resistance are equal.

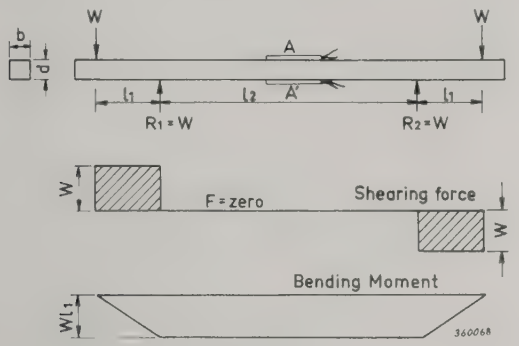


Fig. 57. Simply supported beam with two-point loading.

The maximum strain, e, which exists in the surface layers of the beam can be measured and this will also be constant between R_1 and R_2.
Employing the relationship

$$\frac{f}{y} = \frac{M_b}{I} = \frac{E}{R},$$

where f = maximum intensity of stress in outer layer,
M_b = Bending Moment,
y = half depth of section,
I = Moment of Inertia of section,
E = Young's Modulus,
R = Radius of curvature,

and that Z = Modulus of Section $= \frac{I}{y}$,
the stresses and strain in a beam may be calculated, knowing its physical parameters and conditions of loading.

Experiment with a Rectangular Iron Beam.
The beam was arranged as in Fig. 57
l_1 = 210 mm. l_2 = 490 mm.

b = 51 mm. d = 9.5 mm.
W = 5.2 kg. $E = 2.07 \times 10^6$ kg/cm².

Strain gages were placed above and below the beam to measure the tensile and compressive strain, the Strain Gage Apparatus reading being halved because there were two active gages. The gage factor, k = 2.51. After balancing in the normal way the load was applied and a meter reading of 135 μStrain noted.

$$e = \tfrac{1}{2} \times 135 = 67.5\ \mu\text{Strain.}$$

Maximum bending stress $f = e \times E = 67.5 \times 10^{-6} \times 2.07 \times 10^6$
$= 139.7\ kg/cm^2.$

Now $$M_b = \frac{fy}{I} = f.\ Z$$

and $$Z = \frac{I}{y} = \frac{bd^3}{12} \times \frac{2}{d}$$
$$= \frac{bd^2}{6}$$
$$= \frac{51 \times 9.5^2}{6} = 0.765\ cm^3.$$

Bending Moment = 139.7 × 0.765 = 107 kg.cm.
Checking, it is found that the Bending Moment = $W.l_1$
$= 5.2 \times 21.0$
= 109 kg.cm.

This slight deviation of 2 % is the experimental error which might be expected, and may be due to the Modulus of Elasticity being other than the stated value.

Measurement of Torsion.

Much useful information may be obtained by measuring the effects of stresses at the surface of rotating shafts. The Horse Power transmitted is directly related to the R.P.M. and the shear stress present in the shaft. As it is relatively easy to measure both these quantities it is practicable to obtain information from machines working under normal conditions. It is possible, for example, to determine the efficiency of a marine propeller, the useful H. P. transmitted up to the time of cavitation, being of interest to designer and user.

When a shaft is subjected to couple, the axis of which coincides with that of the shaft, a condition of pure torsion exists. A point in a cross section will be subjected to a pure shear stress. The stress is totally tangential across two planes which pass through the point, one being perpendicular to the shaft axis and the other passing through the shaft axis.

If a small square block of a material is subjected to a shear stress of intensity "q" it can be shown that the intensity of normal stress on the diagonals is equal to "q", but that on one diagonal a condition of pure tension will exist, and on the other pure compression.

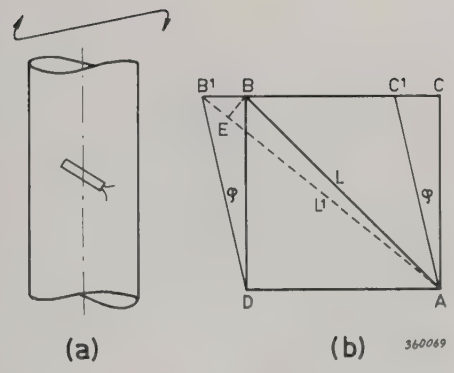


Fig. 58. Shear stress diagram.

Torsion under Static Conditions. In Fig. 58a, a gage has been placed at 45° to the main axis of the shaft and along the principal axis of tensile strain. If the couple is now applied to the shaft, and the surface flattened, as in Fig. 58b, the effect of the strain on one conductor "L" may be observed. In the unstressed condition "L" forms the diagonal of the square BCAD, under load the square becomes the parallelogram B^1C^1AD. A line drawn perpendicular to AB^1 and passing through B forms the point E on AB^1; now as the strains are small quantities, line BE is almost the same as an arc centred at A. The shear strain, φ radians, is $\frac{BB^1}{BD}$ and is equal to $\frac{q}{N}$, where q is the shear stress and N is the Modulus of Rigidity.

$$N = \frac{q}{\varphi} = \frac{\text{shear stress}}{\text{shear strain}}$$

The elongation of "L", the quantity which may be measured, is B^1E, and hence the linear strain is

$$\frac{EB^1}{AB} = \frac{BB^1 \times \frac{1}{\sqrt{2}}}{BD \times \sqrt{2}} = \frac{1}{2}\frac{BB^1}{BD} = \frac{1}{2}\varphi = \frac{1}{2}\frac{q}{N}$$

This quantity $\frac{1}{2}\varphi$ or $\frac{1}{2}\frac{q}{N}$ is the value which is read off the Strain Gage Apparatus.

Example:—

A brass tube with external diameter $D_1 = 25.5$ mm., and an internal diameter $D_2 = 23.5$ mm. is fastened at one end and has a torsional load applied to the other.

Measurement is made with two active gages as shown in Fig. 59.

Gage Factor $k = 2.52$.

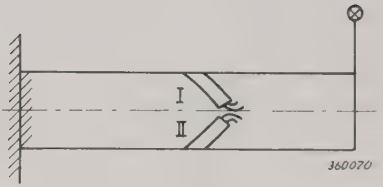


Fig. 59. Fixed torsion specimen.

The reading on the Strain Gage Apparatus is 160 μStrain, i.e.

$$\frac{1}{2}\frac{q}{N} = 80 \therefore \frac{q}{N} = 160$$

The modulus of Elasticity of the brass used was 12.200 kg/mm^2.

Poisson's Ratio $\sigma = \frac{1}{m} = 0.331$.

The Modulus of Rigity,

$$N = \frac{E}{2(1+\frac{1}{m})} = 4.580 \text{ kg/cm}^2.$$

From the relationship:

$$\frac{T}{I_p} = \frac{fs}{R}$$

where T is the torque, I_p the polar moment of Inertia, fs the maximum shear stress, and R the outside radius, it is possible to find the applied torque.

$$I_p = \pi \left(\frac{D_1^4 - D_2^4}{32}\right)$$

$$= \pi \left(\frac{2.55^4 - 2.35^4}{32}\right) = 1.55 \text{ cm}^4$$

$$q = fs = 160 \times 10^{-6} \times 4580 \times 1000 \times 100$$

$$= 160 \times 458$$

$$= 73.3 \text{ kg/cm}^2$$

$$T = \frac{1.155 \times 73.3}{1.275} = 66.4 \text{ kg.cm.}$$

The torque was produced by a weight of 1.6 kg on a moment arm of 41.2 cm. As a check

$$T = 1.6 \times 41.2 = 65.8 \text{ kg.cm.}$$

The results agree to within less than 1 %.

The single force applied has produced bending in the tube as well as torsion, the effects of this bending have, however, been cancelled out by using two suitably placed active gages.

Torsion under Dynamic Conditions. When measuring strains in shafts under dynamic conditions the general instrumentation remains as previously dis-

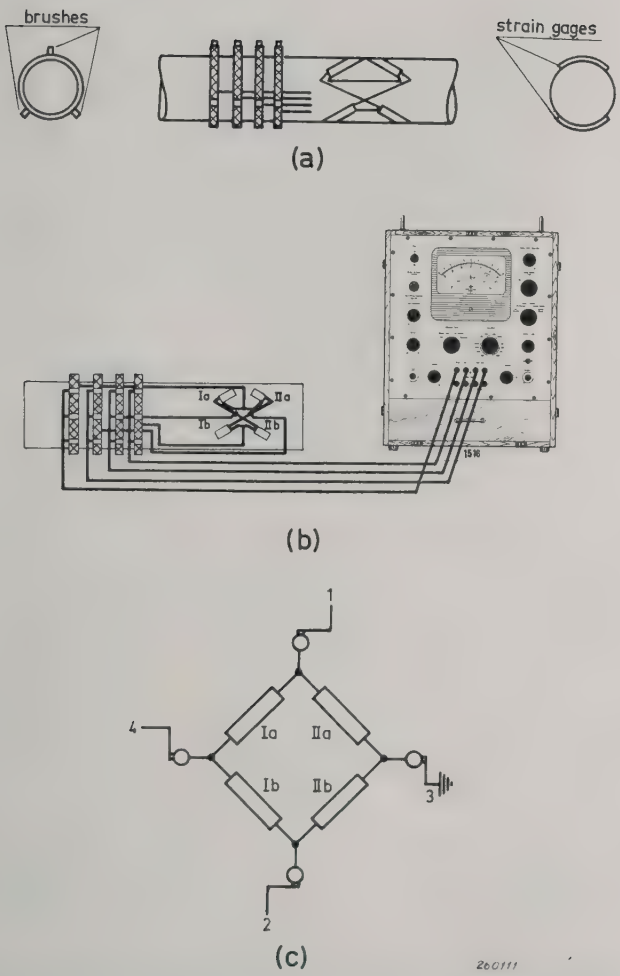


Fig. 60. Measurement of torsion under dynamic conditions, bending compensation applied. 4 active gages.
(a) Mounting of gages and slip rings.
(b) Strain gage connection.
(c) Theoretical circuit.

cussed, there is, however, one important addition. In order to energize the bridge circuit and to lead out the signal, slip rings must be fitted. To prevent the slip rings from being included in the bridge circuit the complete bridge is mounted on the shaft; such a system will give temperature compensation and may be arranged to eliminate the effects of bending.

In order to reduce contact resistance and noise, it is advisable to fit two or three brushes per slip ring. Stainless steel slip rings with silver carbon brushes may be used up to surface speeds of 1200 metres/min. For surface speeds above 1200 metres/min. silver slip rings, and silver-carbon or mercury brushes, will be necessary; Fig. 60a shows the general arrangement. It should be noted that to obtain complete freedom from the effects of bending the gages should be mounted diametrically opposed; Fig. 60b shows the shaft "unwrapped", and a wiring system which may be employed; Fig. 60c is the schematic bridge diagram.

Spectrum Analysing of Dynamic Measurements.

In for example dynamic measurements, it may be of great interest to analyse the signal from the Strain Gage Apparatus as a function of frequency. This

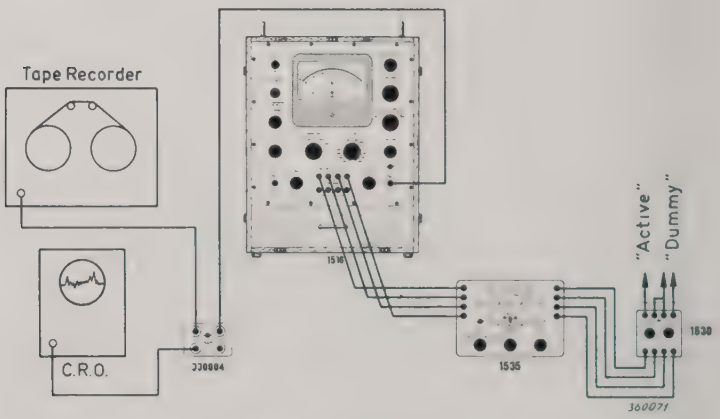


Fig. 61. Measuring arrangement used for recording of dynamical strain measurements.

may be performed by recording the signal during measurement on a tape recorder, and thereafter analysing the signal on the tape by means of such an instrument as the B & K Audio Frequency Spectrum Recorder Type 3313

In Fig. 61 is sketched a measuring arrangement suitable for the recording of dynamic measurements by a tape recorder.
The frequency analysis of the measuring result is carried out, utilizing the set-up shown in Fig. 62.
The frequency spectrum obtained from measurements made on the dynamic stress of a connecting rod in a one cylinder four-stroke combustion engine

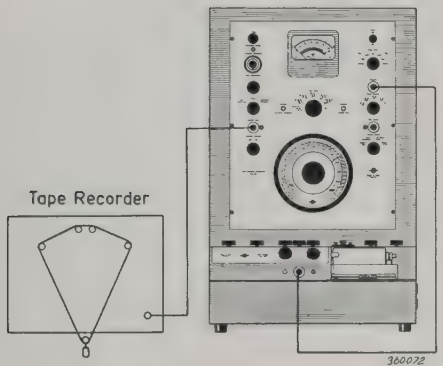


Fig. 62. Equipment employed to frequency-amplitude analyse the dynamic strain signal.

is shown in Fig. 63. To get all the frequency components within the range of the analysing equipment, the tape was played back with a 10 times higher speed than when recorded. The different magnitudes are given in dB relative to 15 μStrain.
For further information concerning analysing of dynamic strain measurements, the reader is referred to the B & K Technical Review, No. 3, July 1959.

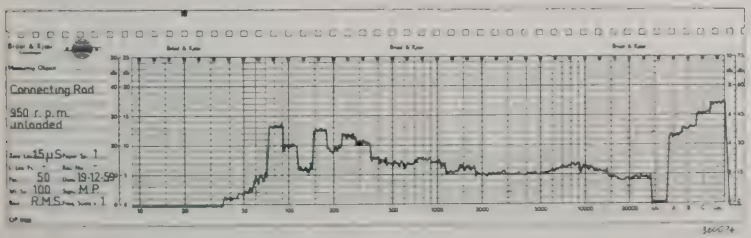


Fig. 63. Spectrogram of dynamic strain signal.

Weighing by the Strain Gage Apparatus using Unbonded Strain Gages

The system shown in Fig. 64 consists, in principle, of a pre-stressed wire, to the centre of which is attached a weighing arm. The arm is balanced on a knife edge support and the application of load "W" to the free end of the arm causes R_1 to be compressed, and R_2 to be stretched. Because wire dimensions make the application of a direct axial compression impractical it is

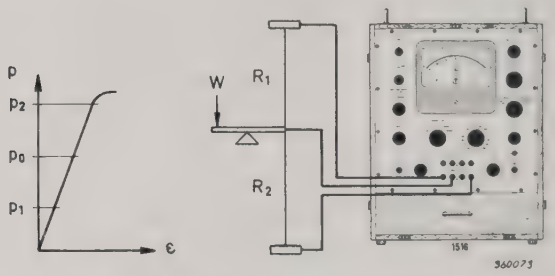


Fig. 64. Strain Gage Apparatus with two unbonded gages for weighing.

necessary to pre-stress the wire, and in order to achieve the maximum useful range the wire is pre-stressed to p_0, which corresponds to the centre of the stress-strain curve, within the elastic limit. Stresses p_1 and p_2 correspond to the stresses in the resistance wires R_1 and R_2 with maximum loading. Limit stops are fitted to the weighing arm to prevent the wires from being destroyed. Such a system would normally be calibrated using standard weights The sensitivity has been doubled by the use of two resistive elements

Measurement of Fluid Levels and Wave Heights.

The level of a fluid may be measured using a Strain Gage Apparatus Type 1516 with a resistive or capacitive probe. The level, or changes in level, may be recorded on the Level Recorder Type 2305 connected to the Type 1516 Typical practical problems are the measurement of wave heights in model harbours and the level of fluid in sealed tanks.

Resistive Probe. The principle shown in Fig 65 may be used. A Level Recorder will record the variation in the resistance of the bridge arm occasioned by the rise and fall of fluid level. Because of the great sensitivity of the Strain Gage Apparatus, the resistance variation ΔR can be small in comparison with the bridge resistance. The registering scale will thus be linear when a linear potentiometer is used on the Level Recorder One

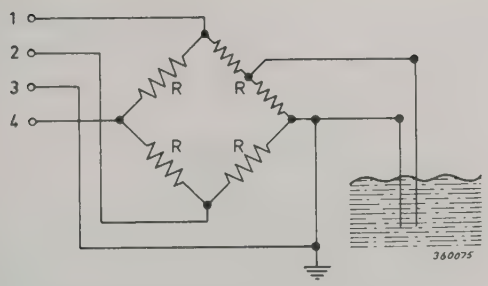


Fig. 65. Resistive detector (fluid).

factor likely to introduce error is that the fluid conductivity may vary due to a change in temperature. A change in conductivity will result in a zero shift, and a change of sensitivity. The former point may be compensated for by means of a "dummy" electrode, which is completely immersed in the fluid and connected to the appropriate bridge arm; however, this does not correct for the change in sensitivity.

Capacitive Probe. The principle of an alternative system, whereby a capacitive probe is used, is illustrated in Fig. 66. An insulated electrode is immersed in the fluid, electrical connection already existing between earth, terminal 3 on the Strain Gage Apparatus, and the liquid. A capacitance exists between the fluid and the electrode, the electrode insulation forming the dielectric. The capacity of the capacitor will be directly proportional to the length of the probe immersed, and hence to the height of the fluid; variations in conductivity of the liquid will have no effect.

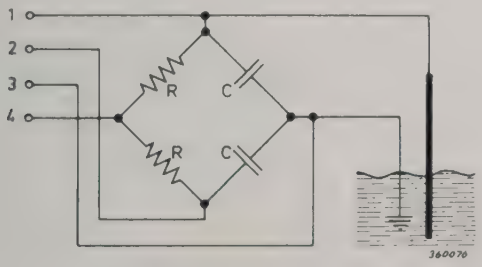


Fig. 66. Capacitive detector (fluid).

Normally the Strain Gage Apparatus is insensitive to changes in capacity, but if two resistor arms are replaced by capacitors, as in Fig. 66, measurement would appear to be possible. However, capacitors of approximately

0.05 μF would be necessary if the hum were to be effectively blocked, and reasonable balancing conditions to exist. In practice it has been found that capacitors of such size are not sufficiently stable to permit the use of maximum amplification in the equipment.

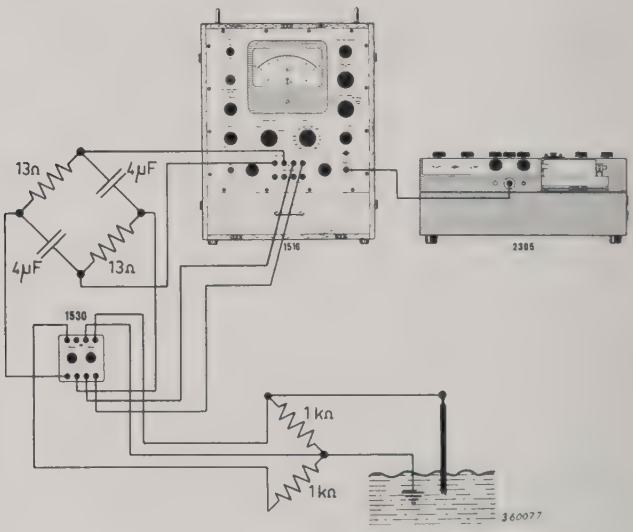


Fig. 67. Phase-shift system.

The most effective solution to the problem is to shift the phase of the bridge voltage by 90°. Fig. 67 shows just such an arrangement. A phase shifting network, consisting of two capacitors of 4 μF and two resistors of 13 Ω, is inserted between the Strain Gage Apparatus and the Balancing Units. The R- and C-balance in the Strain Gage Apparatus are switched off by turning the BALANCE potentiometer to "Off". Once laid, the cables should not be moved, otherwise changes in capacity and self-induction will result.

Appendix

Correction Curves.

It may be safely stated, that in the majority of applications, strain gages with resistance values in the range of 50—250 Ω will be employed. A further analysis of the range would show that a very large percentage of these gages would be grouped around 120 Ω.

In all bridge balancing systems where the balance components constitute an integral part of the bridge, the effectivity of the components will be governed by the values to be balanced. In an effort to obtain a reasonable compromise in the Strain Gage Apparatus Type 1516 the apparatus is equipped with balancing components that are most suitable for 100 ohm strain gages.

The values of resistive balancing components must be such, that they accommodate the normal manufacturing tolerance that manufacturers ascribe to their gages, and also a reasonable amount of out-of-balance introduced by asymmetrical wiring resistance. Here lies the basic problem, in that the balancing component must be able to influence the bridge balance and yet at the same time have no adverse effect on the measuring accuracy. Obviously both conditions cannot be satisfied over a wide range of gage resistance because of the shunting effect.

In some special applications, such as the strain gaging of rotating shafts, the supply to the gage bridge, and the output signal are conducted through slip rings. Owing to the variations in resistance that occur between the slip rings and brushes it is advisable to use high resistance strain gages. In so doing it may be necessary to apply some form of compensation for the shunting effect from the balancing resistors. Fortunately, in the Strain Gage Apparatus Type 1516 this is a simple matter, as the correction can be incorporated by changing the gage factor set on the apparatus by the correction factor α, whereby the reading on the indicating meter will show the correct value.

In Fig. 68 is given a set of curves, showing the correction factor α versus strain gage resistance R with three different values of balancing resistance as a parameter.

The curves are not only valid for one active gage but can also be made use of by two active gages. See below. The parameters refer to the R-BALANCE in the middle position (12.5 kΩ) and the extreme positions (10 kΩ and 15 kΩ). It is seen that when R-BALANCE is in the middle position "12.5 kΩ" α is greater than 1 for strain gages having resistances lower than 100 Ω and smaller than 1 for resistances higher than 100 Ω. This occurs because the

Strain Gage Apparatus is factory adjusted according to 100 Ω strain gages, and with the balancing components (R-BALANCE and C-BALANCE) in circuit and in the middle position.

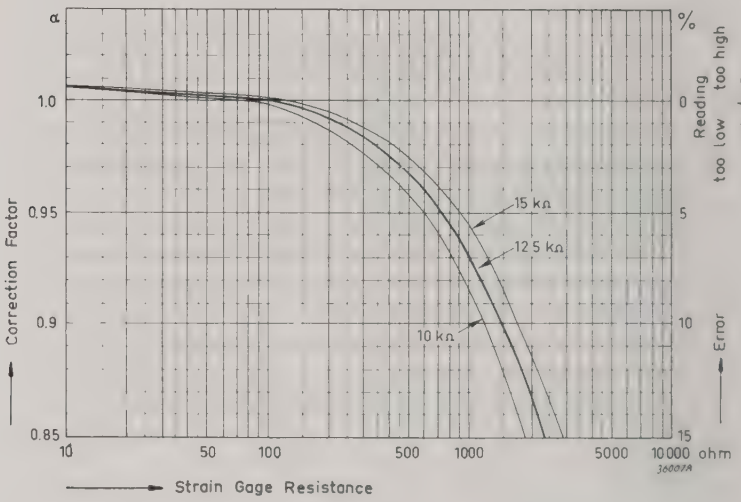


Fig. 68. Correction factor α for gage factor setting.
"12.5 kΩ" to be used by 1 active gage for R-BALANCE in middle position.
"12.5 kΩ" can be used for 2 active gages (half bridge) for any setting of R-BALANCE.
"10 kΩ" and "15 kΩ" to be used by 1 active gage for R-BALANCE in the extreme anticlockwise and clockwise position respectively.

The Curves are used as follows:—

1 active gage (connected to "Active").
R-BALANCE in middle position: Read α on the curve "12.5 kΩ".
R-BALANCE fully anticlockwise: Read α on the curve "10 kΩ".
R-BALANCE fully clockwise: Read α on the curve "15 kΩ".

2 active gages (connected to terminal set "II").
R-BALANCE in any position: Read α on the curve "12.5 kΩ" which gives the correction factor with a negligible error for practical use.

Example I:
1 active gage.
Gage resistance: 800 Ω.
Gage factor: 2.14.
R-BALANCE: Middle position.
On the curve "12.5 kΩ" in Fig. 68 is read for α: 0.945.
The Strain Gage Apparatus should then be adjusted to a gage factor of 2.14 × 0.945 = 2.02.

If the gage factor 2.14 cannot be corrected as above, the error in reading off the indicating meter would be 5.4 % too low, which is read on the "12.5 kΩ" curve by the "% error" scale. (Left ordinate in Fig. 68).

Example II:

1 active gage.
Gage resistance: 10 Ω.
Gage factor: 2.00.
R-BALANCE: Fully clockwise.
On the curve "15 kΩ" in Fig. 68 is read as α : 1.007.
The Strain Gage Apparatus is in this case adjusted to the gage factor of:
$2.00 \times 1.007 = 2.01$.

Example III:

2 active gages. (Half bridge configuration).
Gage resistance: 1000 Ω.
Gage factor: 2.20.
R-BALANCE: Fully anticlockwise.
On the curve "12.5 kΩ" in Fig. 68 is read as α: 0.93.
The Strain Gage Apparatus should then be adjusted to a gage factor of:—
$2.20 \times 0.93 = 2.05$.

The curves illustrate, that for measurements demanding high precision it is necessary that firstly the resistance of the dummy gage and active gage should lie as close to each other as possible, whereby the R-BALANCE potentiometer is near its middle position. Secondly, the gage resistance should, if possible, be around 100 Ω, which gives a reading where no correction is necessary. See paragraph "Matching Strain Gages", page 65 When utilizing the Fixed Balancing Resistor ZR 1540, care should be taken when this is applied so that it parallels the active gage, as in this case the error in reading will be larger than that by the "10 kΩ" curve in Fig. 68.

Stabilizing of Power Supply Voltage for Strain Gage Apparatus.

Variations in the power supply voltage may introduce a perceptible error in the measurements. Consequently, it is recommended to check the calibration of the apparatus during measurements when high precision is required. This is readily done by changing the RANGE μSTRAIN switch to position "Gage Factor" and to check if the deflection has changed. For power supplies where the voltage experiences heavy variations, the voltage should be stabilized before being supplied to the equipment.

Terminology

General.

Used in 1516 Manual.	*Meaning.*	*Known Alternative Symbols.*	*Units.*
R.	Resistance.		Ohms.
ϱ	Specific Resistance.		Ohm. cm.
a.	Area.	q, F.	cm^2
b.	Width or breadth of Section.		cm.
d.	Depth of Section.	h.	cm.
l.	Length.		cm.
W.	Weight.		kg.
Δ	A small change of a quantity.		
k.	Gage factor.	F, S.	
$\frac{1}{m}$	Poisson's Ratio.	σ, μ, ν.	
V.	Voltage.	U, u.	volts.

Direct and Bending Stress.

Used in 1516 Manual.	*Meaning.*	*Known Alternative Symbols.*	*Units.*
P.	Pull or Thrust.		kg.
M.	Bending Moment.	M_b	kg cm.
E.	Young's Modulus.		kg cm^2
R.	Radius of Curvature.	ϱ	cm.
I.	Moment of Inertia. (2nd Moment of Area).		cm^4
Z.	Modulus of Section.	W_b	cm^3
y.	Distance of surface from Neutral axis.	e.	cm.
e.	Tensile or Compressive Strain.	$\varepsilon = \frac{1}{\alpha}$	cm./cm.
p.	Stress at any point in a cross-section.	σ	kg/cm^2
f.	Extreme value of stress (skin).		kg/cm^2
ft.	Tensile skin stress.		kg/cm^2
fc.	Compressive skin stress.		kg/cm^2
q.	Shear stress.	τ_s	kg/cm^2

Torsion.

Used in 1516 Manual.	*Meaning.*	*Known Alternative Symbols.*	*Units.*
T.	Torque.	W. J.	kg.cm.
N.	Modulus of Rigidity.	G, C.	kg/cm^2
D	Diameter of shaft.	d	cm.
R.	Radius of shaft.	c.	cm.
I_p	Polar Moment of Inertia.	J.	cm^4
φ	Shearing Strain.	γ	Radians.
fs.	Shear Stress at Surface.	τ_a	kg/cm^2

Specifications

Strain Gage Apparatus Type 1516.

BRIDGE VOLTAGE:
Internal: AC, o.3, 1.0 and 3.0 volts, 3 kHz.
External: DC from DC Bridge Supply Unit Type 1535 for dynamic measurements at higher frequencies.

GAGE FACTOR:
Continuous adjustment between 1.5—3
Other gage factors by correction.

SENSITIVITY RANGES (full meter deflection):
1 active gage:—
Bridge voltage 3 V: 100, 300 1ooo and 3ooo μStrain.
Bridge voltage 1 V: 300, 1ooo, 3ooo and 10ooo μStrain.
Bridge voltage o.3 V: 1ooo, 3ooo, 10ooo and 30ooo μStrain.

4 active gages:—
Four times the sensitivity obtainable, readings are then divided by four.

ACCURACY:
1.5 % of full deflection.
For dynamic measurements the frequency characteristic is within $\pm$ 1 dB from 20 Hz to 100 kHz.

STRAIN GAGES:
All forms of resistive types.
Resistance range: 10 Ω — 1ooo Ω.

INDIVIDUAL BALANCING COMPONENTS:

C-balancing,
Variable capacitor. Unbalance in outside circuit, maximum 400 pF.

R-balancing,
Wire-wound potentiometer.
Maximum difference in gage resistance R between the two gages in half bridge condition:
$3 \times R \times 10^{-3}$ %.

RANGE OF DYNAMIC MEASUREMENTS:
0—300 Hz employing internal bridge voltage.
20 Hz—100 kHz employing external DC Bridge Supply Unit Type 1535.

INDICATING METER:	Moving coil instrument. Protected against overload. Subsidiary gage factor scale. Illuminated scales.
POWER SUPPLY:	100—115—127—150—220 and 240 Volts AC.
Frequency,	40—400 Hz.
Consumption,	Approximately 65 Watts.
CABINET:	Mahogany cabinet, with handles and lid. Drawer for accessories, balancing units, strain gages and adhesive.
DIMENSIONS:	50 (height) × 40 (width) × 20 (depth excl. knobs) centimetres. 20 (height) × 16 (width) × 8 (depth excl. knobs) inches.
WEIGHT:	22 kg (48.5 lbs.).
ACCESSORIES:	The Units 1530, 1531, ZR 1540, and ZR 1541 are supplied with the apparatus.

Automatic Selector Type 1542.

TYPE OF STRAIN GAGES:	Resistive, Resistance range 10 Ω—1000 Ω
INDIVIDUAL BALANCING COMPONENTS:	
C-Balancing,	Variable capacitor. Unbalance in outside circuit maximum 400 pF.
R-Balancing,	10-turn, wire-wound potentiometer. Maximum difference in gage resistance R between the two gages in half bridge condition: $3 \times R \times 10^{-3}$ %.
STATIC AND DYNAMIC MEASUREMENTS:	Identical to Strain Gage Apparatus Type 1516.

50-POSITION SWITCH: Allows up to 50 bridges to be tested successively. Means for connection of two Twenty-Point Panels Type 1543, thereby utilizing all 50 positions.

FAST RETURN ARRANGEMENT: Covering measuring points not used. Adjustable over an arbitrary number of successive positions. Stops in position A1.
Time interval between each switching: Approximately 0.1 sec.
Can be switched non-operable.

MEASURING-TIME INTERVALS: Selectable in four steps of 0.5, 1, 2, or 4 sec. within each measuring position.
Accuracy $\pm$ 25 %.

10 TERMINAL SETS: Permanently connected with section A on the 50-Position Switch.
For connection of 10 full or half strain gage bridges. 2 highly stable precision resistors (100 Ω) for each terminal set when in half bridge configuration.

MARKING: When position A1 is switched in, information is made available by a relay contact via the REMOTE CONTROL jack.

REMOTE CONTROL: Switching action of 50-Position Switch can be remotely controlled. Fast return operational.

POWER SUPPLY: 100, 115, 127, 150, 220 or 240 volt AC. Selectable by switch. Voltage variations, $\pm$ 10 %.

Frequency, 40—400 Hz.

Consumption, Approximately 15 watt.

CABINET: Mahogany cabinet with handles and lid.

DIMENSIONS: 50 (height) $\times$ 40 (width) $\times$ 20 (depth excl. knobs) centimetres.
20 (height) $\times$ 16 (width) $\times$ 8 (depth excl. knobs) inches.

WEIGHT: 15 kg (33 lbs.).

Twenty-Point Panel Type 1543.

(Accessory for Automatic Selector Type 1542)

TYPES OF STRAIN GAGES: Resistive. Resistance: 10 Ω—1000 Ω.

INDIVIDUAL BALANCING COMPONENTS:

C-Balancing, Variable capacitator.
Unbalance in outside circuit, maximum 400 pF.

R-Balancing, 10-turn, wire-wound potentiometer.
Maximum difference in gage resistance R between the two gages in half bridge condition:
$3 \times R \times 10^{-3}$ %.

STATIC AND DYNAMIC MEASUREMENTS: Same as the Strain Gage Apparatus Type 1516.

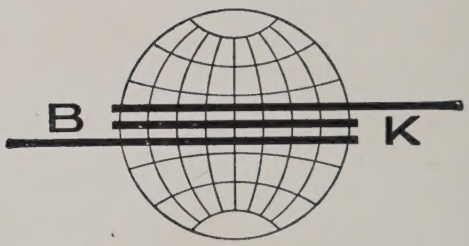
20 TERMINAL SETS: For connection of 20 full or half strain gage bridges. 2 highly stable precision resistors (100 Ω) for each terminal set when in half bridge configuration.

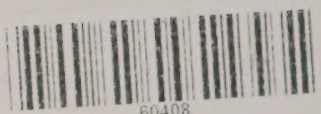
CABINET: Mahogany cabinet with handles and lid.

DIMENSIONS: 50 (height) × 40 (width) × 20 (depth excl. knobs) centimetres.
20 (height) × 16 (width) × 8 (depth excl. knobs) inches.

WEIGHT: 15 kg (33 lbs.).

ACCESSORIES INCLUDED: 2 × 30-cored cable with plugs, AO 0030.

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